



Observation of Electroweak Production of a Same-Sign W Boson Pair in Association with Two Jets in pp Collisions $\sqrt{s}=13$ TeV with the ATLAS Detector

ATLAS

Published in:
Physical Review Letters

DOI:
[10.1103/PhysRevLett.123.161801](https://doi.org/10.1103/PhysRevLett.123.161801)

Publication date:
2019


Document version
Publisher's PDF, also known as Version of record

Document license:
[CC BY](#)

Citation for published version (APA):
ATLAS (2019). Observation of Electroweak Production of a Same-Sign W Boson Pair in Association with Two Jets in pp Collisions $\sqrt{s}=13$ TeV with the ATLAS Detector. *Physical Review Letters*, 123(16), [161801]. <https://doi.org/10.1103/PhysRevLett.123.161801>

Observation of Electroweak Production of a Same-Sign W Boson Pair in Association with Two Jets in pp Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector

M. Aaboud *et al.**
(ATLAS Collaboration)

 (Received 10 June 2019; published 15 October 2019)

This Letter presents the observation and measurement of electroweak production of a same-sign W boson pair in association with two jets using 36.1 fb^{-1} of proton-proton collision data recorded at a center-of-mass energy of $\sqrt{s} = 13$ TeV by the ATLAS detector at the Large Hadron Collider. The analysis is performed in the detector fiducial phase-space region, defined by the presence of two same-sign leptons, electron or muon, and at least two jets with a large invariant mass and rapidity difference. A total of 122 candidate events are observed for a background expectation of 69 ± 7 events, corresponding to an observed signal significance of 6.5 standard deviations. The measured fiducial signal cross section is $\sigma^{\text{fid}} = 2.89_{-0.48}^{+0.51}(\text{stat})_{-0.28}^{+0.29}(\text{syst}) \text{ fb}$.

DOI: [10.1103/PhysRevLett.123.161801](https://doi.org/10.1103/PhysRevLett.123.161801)

The scattering of two massive vector bosons (VBS), $VV \rightarrow VV$ with $V = W$ or Z , is an important process for studying the mechanism of electroweak symmetry breaking [1–3]. VBS processes involve quartic gauge-boson self-interactions, and the s - and t -channel exchanges of a gauge or Higgs boson. The Higgs boson regularizes the VBS amplitude by canceling out the divergencies arising from longitudinally polarized vector bosons at high energy [4,5]. These cancellations depend on the gauge structure of the theory and are exact in the standard model (SM) [6,7]. The present measurement of W boson scattering thus serves as a fundamental probe of the SM electroweak theory.

At the LHC, the VBS final state of two gauge bosons and two jets ($VVjj$) can be produced via two classes of mechanisms. The first class, referred to as strong production, involves both strong and electroweak interactions at Born level, and features diagrams where the incoming partons exchange color, as illustrated in Fig. 1(b). The second class, referred to as electroweak production, involves only weak interactions at Born level [8] and includes VBS diagrams. Figure 1(b) shows a typical VBS diagram where the gauge bosons are radiated off the incoming quarks and then scatter via the quartic self-interaction vertex. In VBS processes, the incoming partons do not exchange color and typically produce the two jets with a large invariant mass and with large rapidity difference [9].

The $W^{\pm}W^{\pm}jj$ final state has the largest ratio of electroweak to strong production cross sections compared to other VBS diboson processes [3]; this is because at leading-order (LO) accuracy in perturbative quantum chromodynamics (QCD) quark-gluon and gluon-gluon initiated diagrams are absent and contributions from quark and (anti)-quark annihilation diagrams are suppressed. This ratio is of order five in the fiducial phase-space region of this analysis. The s -channel VBS diagrams with trilinear self-interactions are absent in this final state. In addition, electroweak diagrams not involving self-interactions are suppressed [10], thus enhancing sensitivity of this final state to gauge-boson self couplings. Previously, an observation of $W^{\pm}W^{\pm}jj$ electroweak production was reported by the CMS Collaboration [11] and evidence was reported by the ATLAS Collaboration using a smaller dataset [12,13].

This Letter presents the observation and measurement of the electroweak production of $W^{\pm}W^{\pm}jj$ events in which both W bosons decay into an electron or muon and a

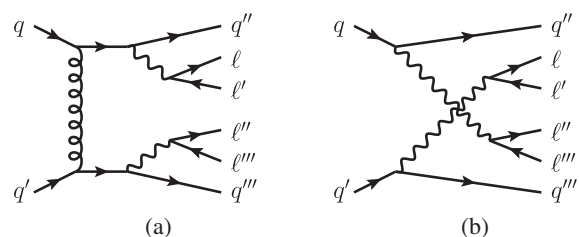


FIG. 1. Representative diagrams for $VVjj$ production where two electroweak gauge bosons are radiated off quarks. (a) Strong production diagrams involve both electroweak and strong interactions without gauge boson self-interactions. (b) In VBS diagrams, the gauge bosons can interact via gauge-boson self-interactions, e.g., a quartic W boson vertex.

*Full author list given at the end of the article.

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/) license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP³.

neutrino. This study uses 36.1 fb^{-1} of proton-proton (pp) collision data collected by the ATLAS detector at $\sqrt{s} = 13 \text{ TeV}$. The ATLAS detector [14] is a multipurpose particle detector with a forward-backward symmetric cylindrical geometry and almost 4π coverage in solid angle [15]. The inner tracking detector (ID) covers $|\eta| < 2.5$ in pseudorapidity and consists of a silicon pixel detector, a silicon microstrip detector, and a transition radiation tracker. The ID is surrounded by a superconducting solenoid magnet and an almost hermetic calorimeter system, which provides three-dimensional reconstruction of particle showers up to $|\eta| = 4.9$. The muon spectrometer (MS) has three air-core toroidal magnets: a barrel toroid and two end cap toroids. Three layers of precision tracking stations with drift tubes and cathode strip chambers allow precise muon momentum measurement up to $|\eta| = 2.7$. Resistive-plate and thin-gap chambers provide muon triggering capability up to $|\eta| = 2.4$.

Monte Carlo (MC) simulation is used to generate signal and background predictions. The generated events are processed through a detector simulation [16] based on GEANT4 [17] and are reconstructed using the same algorithms as used for data. The simulation includes the effect of multiple pp interactions per bunch crossing as detailed in Ref. [18].

Processes producing four leptons were simulated using the event generator SHERPA v2.2.2 [19–22] with the NNPDF3.0NNLO [23] set of parton distribution functions (PDF). Electroweak diboson production in association with two jets was simulated with diagrams including exactly six orders of the EW coupling [24]. The simulation of the strong production processes includes diagrams with exactly four electroweak (EW) vertices [25]. The simulation of both the $W^\pm W^\pm jj$ electroweak signal and $W^\pm W^\pm jj$ strong background processes includes up to one additional parton at LO in QCD. For $\ell\ell\ell\nu$ and 4ℓ final states, matrix elements include up to one parton at next-to-leading order (NLO) and three partons at LO in QCD. All multileg processes were simulated combining the various final-state topologies with the MEPS merging algorithm [22,26] and matched to the SHERPA internal parton shower, hadronization, and underlying-event modeling [21,27]. The renormalization and factorization scales were set to the invariant mass of the four-lepton system at the matrix-element level. A signal sample for alternative theoretical predictions was simulated with POWHEG-BOX [28–31] and PYTHIA8.230 [32] at NLO QCD accuracy and employing the VBS approximation [33], the NNPDF3.0NNLO PDF set, and renormalization and factorization scales set to the W boson mass. The $V\gamma$ processes were simulated with exactly three EW vertices using SHERPA v2.1.1 at NLO (up to one parton) or LO accuracy (up to three partons) using the CT10NLO PDF set [34]. Electroweak $V\gamma jj$ processes were simulated using SHERPA v2.2.4 with the NNPDF3.0NNLO PDF set,

with exactly five orders of the EW coupling, and at LO QCD accuracy. The triboson production processes were simulated with SHERPA v2.1.1 and the CT10NLO PDF set. MADGRAPH5_AMC@NLO [35] with NNPDF3.0NNLO PDF set and PYTHIA8.210 were used to simulate $t\bar{t}V$ processes at NLO QCD accuracy.

The $W^\pm W^\pm jj$ electroweak production cross section is measured in a fiducial region defined at the particle level in MC simulation by requiring exactly two same-sign leptons with a transverse momentum, p_T , greater than 27 GeV and $|\eta| < 2.5$; leptons are defined as electrons and muons produced in W boson decays and that do not originate from τ decays. The lepton four-momentum includes the four-momenta of photons inside a cone of size $\Delta R = 0.1$ around the lepton. The two leptons must be separated by a distance of $\Delta R_{\ell\ell} > 0.3$ and must have an invariant mass, $m_{\ell\ell}$, greater than 20 GeV. The magnitude of the vector sum of the transverse momenta of the two final-state neutrinos with highest p_T must be greater than 30 GeV. Jets are reconstructed using the anti- k_t algorithm [36] with radius parameter $R = 0.4$ and using all final-state particles, except for neutrinos and charged leptons from W boson decays. Jets are required to have $p_T > 35 \text{ GeV}$ and $|\eta| < 4.5$. Events with a charged lepton that is within a cone of radius $\Delta R_{\ell j} = 0.3$ around a jet are vetoed. The fiducial region requires at least two jets, including one with $p_T > 65 \text{ GeV}$ and another with $p_T > 35 \text{ GeV}$. The two highest- p_T jets must have an invariant mass $m_{jj} > 500 \text{ GeV}$ and a rapidity difference $|\Delta y_{jj}| > 2$.

The fiducial cross section predicted by SHERPA for $W^\pm W^\pm jj$ electroweak production is $2.01^{+0.33}_{-0.23} \text{ fb}$. The uncertainty includes independent variations of the renormalization and factorization scales by factors of 0.5 and 2 with the constraint $0.5 \leq \mu_F/\mu_R \leq 2$ which contribute $^{+14\%}_{-11\%}$; it also includes uncertainties from the NNPDF3.0NNLO ensemble, as well as differences between the CT14 [37] and MMHT2014 [38] PDF sets ($^{+2.5\%}_{-1.5\%}$) [39]. Uncertainties in the parton shower, hadronization, and underlying-event modeling are evaluated by varying the MEPS matching and resummation scales and amount to $^{+8\%}_{-1\%}$. POWHEG+PYTHIA8 predicts a signal fiducial cross section of $3.08^{+0.45}_{-0.46} \text{ fb}$, with the uncertainties derived using the same procedures as for the SHERPA prediction, except for the uncertainty in the parton shower modeling, which is estimated as the difference relative to POWHEG+HERWIG7 [40,41]. The SHERPA electroweak samples suffer from a nonoptimal setting of the color flow, which leads to an excess of central jet emissions from the parton shower. Since up to one additional parton is included in the matrix element of the $W^\pm W^\pm jj$ electroweak sample, the effect on its differential distributions is reduced but accompanied by a significant suppression of the predicted cross section [24].

Events are required to contain at least one reconstructed proton interaction vertex. The vertex with the highest p_T^2 sum of associated ID tracks is selected as the primary vertex. Electrons are reconstructed from energy clusters in the electromagnetic calorimeter that are matched to tracks reconstructed in the ID with the requirement of a hit in the innermost pixel layer [42]. Muon are reconstructed by combining ID and MS information [43]. Electron and muon candidates must satisfy loose identification criteria [42,43], have $p_T > 6$ GeV, and $|\eta| < 2.47$ and $|\eta| < 2.7$, respectively. The ID tracks associated to electron (muon) candidates are matched to the primary vertex by requiring their transverse impact parameter significance to satisfy $|d_0/\sigma_{d_0}| < 5(10)$; the longitudinal impact parameter multiplied by the sine of the polar angle of the lepton candidates must satisfy $|z_0 \sin \theta| < 0.5$ mm. Electrons and muons passing these selections are further referred to as baseline leptons.

Jets are reconstructed from calorimeter energy clusters [44,45] using the anti- k_t algorithm with radius parameter $R = 0.4$. Jets are required to have $p_T > 30$ GeV in the forward region ($2.4 < |\eta| < 4.5$) and $p_T > 25$ GeV in the central region ($|\eta| < 2.4$). Central jets with $p_T < 60$ GeV must be matched to the primary vertex [46]. Jets containing b hadrons (b jets) are identified in the range of $|\eta| < 2.5$ with an efficiency of 85% using techniques described in Ref. [47]. Selected electron, muon, and jet candidates are required to be nonoverlapping using the procedures described in Ref. [18]. The missing transverse momentum, E_T^{miss} , is computed using selected electrons, muons, and jets, and the track-based soft term defined in Ref. [48].

Events are selected online by single-electron or single-muon triggers [49]. Candidate events are selected by requiring exactly two same-sign baseline leptons, electron or muon, with $m_{\ell\ell} > 20$ GeV and by requiring $E_T^{\text{miss}} > 30$ GeV. They are required to contain at least two jets, including one with $p_T > 65$ GeV and another with $p_T > 35$ GeV. Events with at least one identified b jet are rejected in order to reduce background contributions from top-quark pair production ($t\bar{t}$). The two highest- p_T jets are required to have $m_{jj} > 200$ GeV and $|\Delta y_{jj}| > 2$. These jet selection criteria were optimized to separate the $W^\pm W^\pm jj$ electroweak process from the strong production and other background processes.

After these selections, the dominant source of background events is due to leptons originating from decays of heavy-flavor hadrons and jets misidentified as electrons, collectively referred to as nonprompt leptons. Additional selection criteria are applied to reduce their contributions. Signal electrons are required to satisfy tight identification criteria [42], to have $p_T > 27$ GeV, and to be outside the calorimeter transition region ($1.37 < |\eta| < 1.52$). Signal

muons are required to satisfy medium identification criteria [43], and to have $p_T > 27$ GeV and $|d_0/\sigma_{d_0}| < 3$. Signal electrons and muons are further required to be isolated from nearby particles, with isolation criteria defined using calorimeter clusters and ID tracks. These isolation criteria are optimized to have an efficiency of at least 90% for $p_T > 25$ GeV and at least 99% for $p_T > 60$ GeV [42,43]. For dielectron events, the electron pseudorapidity is restricted to $|\eta| < 1.37$ and events with $|m_{ee} - 91.2 \text{ GeV}| < 15$ GeV are discarded. These criteria reduce the background from electron charge misreconstruction described later. Candidate events with exactly two signal leptons are said to pass the full event selection.

The contributions from the WZ , $V\gamma$, ZZ , $t\bar{t}V$, and triboson production are estimated using simulation. The predicted event yields of the WZ and $V\gamma$ processes are normalized to data in dedicated control regions. The normalization of the WZ background is determined using events with exactly three baseline leptons, two of which are required to pass the signal lepton selection, and that satisfy the dijet and E_T^{miss} selection criteria. Events from $V\gamma$ production enter the signal region when a photon is misidentified as an electron. The modeling of this misidentification process in simulation is corrected using $Z \rightarrow \mu^+ \mu^- \gamma$ events where a photon is emitted by a muon and then misidentified as an electron. These events are selected by requiring exactly two opposite-sign signal muons, one signal electron, $E_T^{\text{miss}} < 30$ GeV and a trilepton invariant mass satisfying $75 \text{ GeV} < m_{\mu\mu e} < 100$ GeV. A normalization factor of 1.8 is derived from this control region and used to correct the simulated $V\gamma$ events. To account for the differences between the $Z\gamma$ and $W\gamma$ processes, the full effect of this correction factor is assigned as a systematic uncertainty, corresponding to 44% of the estimated $V\gamma$ yield. The relative contributions from electroweak and strong production of WZ and $V\gamma$ processes are estimated from simulation since this analysis is not sensitive to their different admixtures. Theoretical uncertainties in the predictions of the ZZ , $V\gamma$, triboson, and $t\bar{t}V$ backgrounds vary from 20% to 30% [25,50,51].

Background contributions with nonprompt leptons are estimated by weighting data events from dedicated control regions by scale factors. These scale factors are measured in dijet events containing exactly one lepton that is p_T balanced by a b jet. The b -jet requirement enhances nonprompt lepton contributions and suppresses contributions from W/Z bosons, which are subtracted from data using simulation. The scale factor is defined as the ratio of the number of signal leptons to the number of leptons passing a dedicated background selection. The background leptons are required to pass the baseline lepton selection and fail the signal lepton selection, where background electrons are in addition required to satisfy medium

identification criteria [42]. Moreover, the background electron (muon) p_T is required to be greater than 20(15) GeV. Separate scale factors are computed for muons and for central and forward electrons. In order to reduce the dependence on the underlying p_T spectrum of b jets that produce nonprompt leptons, the scale factors are measured as a function of the scalar sum of the background lepton p_T and the additional activity around the lepton. This activity, p_T^{iso30} , is quantified by the sum of the p_T of ID tracks that are within a cone of size $\Delta R = 0.3$ around the lepton and originate from the primary vertex.

Data events, that are weighted by the scale factors, are taken from control regions defined using the full event selection criteria except that one lepton is required to pass the background lepton selection and its p_T is replaced with $p_T + p_T^{\text{iso30}}$, with this sum required to be greater than 27 GeV. A statistically independent control region is defined for each bin of the m_{jj} distribution. The uncertainty of the estimated nonprompt background yields is approximately 50% in $\mu^\pm\mu^\pm$ final states and varies between 40% and 90% for $e^\pm e^\pm$ and $e^\pm\mu^\pm$ final states. It includes the systematic uncertainty of the scale factors and the statistical uncertainty of the control regions. The former uncertainty is derived from variations in the composition of the dijet control regions where these factors are measured, obtained by varying the selection criteria. The entire method is validated in regions enriched with nonprompt leptons from $t\bar{t}$ (W + jet) events selected by requiring exactly two same-sign leptons and exactly one (zero) b jet among a total of at least (less than) two jets. In these regions, the number of observed data events and the number of predicted background events agree within their uncertainties.

Opposite-sign lepton pairs pass the full event selection when an electron undergoes an interaction with the detector material resulting in incorrect charge reconstruction. The probability of this charge misreconstruction, ϵ_{misrec} , is measured in $Z \rightarrow e^+e^-$ events [42] and it increases from about 0.1% in the central region to a few percent for $|\eta| > 2$. The background contributions from electron charge misreconstruction are estimated from data using opposite-sign lepton pairs that satisfy the full event selection criteria, except for the same-sign requirement; these events are weighted by ϵ_{misrec} and the electron energy loss due to the material interaction is corrected with η -dependent factors derived from simulation [42]. The overall method is validated by comparing the number of observed same-sign electron pairs having $|m_{ee} - 91.2 \text{ GeV}| < 15 \text{ GeV}$ with the predicted background yield, with the two numbers agreeing within the systematic uncertainty of 15%. This uncertainty is dominated by the statistical uncertainty in the measurement of ϵ_{misrec} , which is less than 10% for $|\eta| > 2$ and up to 20% in the central region. The charge misreconstruction of muons is found to be negligible.

The detector systematic uncertainties arising from the mismodeling of the reconstructed objects are estimated primarily from data and their impact on the analysis is assessed using simulated events. The dominant source is the uncertainty of the jet energy scale, which amounts to 2% for the signal and 10% for the WZ background. The uncertainty in the measurement of the integrated luminosity is 2.1% [52].

The theory modeling uncertainties of the m_{jj} distributions predicted by SHERPA for $W^\pm W^\pm jj$ and WZ processes are evaluated using the procedures described above. They account for uncertainties in the total cross section, the acceptance of the fiducial selection, the modeling of the event selection efficiency and the shape of the m_{jj} distribution. Only the latter two affect the measured fiducial cross section of the $W^\pm W^\pm jj$ signal, since absolute normalization uncertainties cancel in this measurement. The uncertainty in the modeling of the event selection efficiency also accounts for extrapolations from the fiducial phase space to the detector level, in particular for the η acceptance in dielectron events. Effects of the NLO electroweak corrections [53] and of the interference between electroweak and strong $W^\pm W^\pm jj$ production [9] are assigned as an uncertainty in the m_{jj} shape of the $W^\pm W^\pm jj$ signal, amounting to 6% and 4%, respectively. This approach is used because no event generator implemented the complete NLO calculation until recently [54] and because the interference contribution is defined only at the leading order [8]. The overlap of the photon radiation in the SHERPA parton shower model with the NLO EW corrections is found to be negligible.

Signal events are categorized by their lepton flavor and charge into six mutually exclusive channels: $e^\pm e^\pm$, $e^\pm\mu^\pm$, and $\mu^\pm\mu^\pm$, in order to exploit their different signal and background compositions. The signal region is defined as $m_{jj} > 500 \text{ GeV}$ and further split into four m_{jj} bins, optimized to increase the expected signal sensitivity. Events with $200 \text{ GeV} < m_{jj} < 500 \text{ GeV}$ serve as additional control regions, dominated by contributions from nonprompt leptons and WZ backgrounds. The resulting 30 bins of the m_{jj} distributions in the signal and control regions are combined in a profile likelihood fit [55] to extract the fiducial cross section.

The signal strength, a free parameter in the fit, multiplies the expected fiducial $W^\pm W^\pm jj$ electroweak production cross section used to produce the signal template. The signal template of reconstructed $W^\pm W^\pm jj$ electroweak events also includes candidate events with electrons and muons produced in W decays into τ lepton. Since the fiducial cross section prediction does not include such events, their fractional contribution predicted by the simulation is removed from the fiducial cross section measurement. Systematic uncertainties are included in the fit as nuisance parameters constrained by Gaussian functions. The WZ control region is also included in the fit as a single

TABLE I. Summary of the data event yields, and the signal and background event yields in the signal region as obtained after the fit. The numbers are shown for the six individual channels and for all channels combined. The backgrounds from $V\gamma$ production and electron charge misreconstruction are combined in the e/γ conversions category. The other prompt category combines ZZ , VVV , and $t\bar{t}V$ background contributions.

	e^+e^+	e^-e^-	$e^+\mu^+$	$e^-\mu^-$	$\mu^+\mu^+$	$\mu^-\mu^-$	Combined
WZ	1.48 ± 0.32	1.09 ± 0.27	11.6 ± 1.9	7.9 ± 1.4	5.0 ± 0.7	3.4 ± 0.6	30 ± 4
Nonprompt	2.2 ± 1.1	1.2 ± 0.6	5.9 ± 2.5	4.7 ± 1.6	0.56 ± 0.05	0.68 ± 0.13	15 ± 5
e/γ conversions	1.6 ± 0.4	1.6 ± 0.4	6.3 ± 1.6	4.3 ± 1.1	13.9 ± 2.9
Other prompt	0.16 ± 0.04	0.14 ± 0.04	0.90 ± 0.20	0.63 ± 0.14	0.39 ± 0.09	0.22 ± 0.05	2.4 ± 0.5
$W^\pm W^\pm jj$ strong	0.35 ± 0.13	0.15 ± 0.05	2.9 ± 1.0	1.2 ± 0.4	1.8 ± 0.6	0.76 ± 0.25	7.2 ± 2.3
Expected background	5.8 ± 1.4	4.1 ± 1.1	28 ± 4	18.8 ± 2.6	7.7 ± 0.9	5.1 ± 0.6	69 ± 7
$W^\pm W^\pm jj$ electroweak	5.6 ± 1.0	2.2 ± 0.4	24 ± 5	9.4 ± 1.8	13.4 ± 2.5	5.1 ± 1.0	60 ± 11
Data	10	4	44	28	25	11	122

bin and the normalization of the WZ background is included as a free parameter. The analysis chooses maximize the expected significance for the $W^\pm W^\pm jj$ electroweak signal predicted by SHERPA at 4.4σ . A significance of 6.5σ is expected by the alternative signal sample simulated with POWHEG-BOX.

Table I compares the numbers of data events in the signal region with the background and signal event yields after the fit; the signal region contains 122 data events, compared with a best-fit yield of 69 ± 7 background events. By fitting the data and background events in the signal and control regions, the background-only hypothesis is rejected with a significance of 6.5σ . Figure 2 shows the control region events separated into categories and the m_{jj} distribution in the signal region after the fit. All nuisance parameters remain within their 1 standard deviation uncertainty after the fit. The normalization of the WZ background is scaled by a factor of $0.86^{+0.07}_{-0.07}(\text{stat})^{+0.18}_{-0.08}(\text{exp syst})^{+0.31}_{-0.23}(\text{mod syst})$, constrained mainly by the observed number of data events

in the WZ control region. Figure 3 shows the $m_{\ell\ell}$ distribution in the signal region after the fit.

A signal strength of $1.44^{+0.26}_{-0.24}(\text{stat})^{+0.28}_{-0.22}(\text{syst})$ is measured with respect to the SHERPA fiducial cross section prediction for $W^\pm W^\pm jj$ electroweak production, where the systematic uncertainty also includes the absolute normalization uncertainty of this prediction. This corresponds to a fiducial signal cross section of

$$\sigma^{\text{fid}} = 2.89^{+0.51}_{-0.48}(\text{stat})^{+0.24}_{-0.22}(\text{exp syst}) \times {}^{+0.14}_{-0.16}(\text{mod syst})^{+0.08}_{-0.06}(\text{lumi}) \text{ fb},$$

where the uncertainties correspond to the statistical, experimental systematic, theory modeling systematic, and luminosity uncertainties, respectively. The experimental systematic uncertainty includes the detector systematic uncertainties and the uncertainties in estimating all background processes except for the WZ and $W^\pm W^\pm jj$ strong

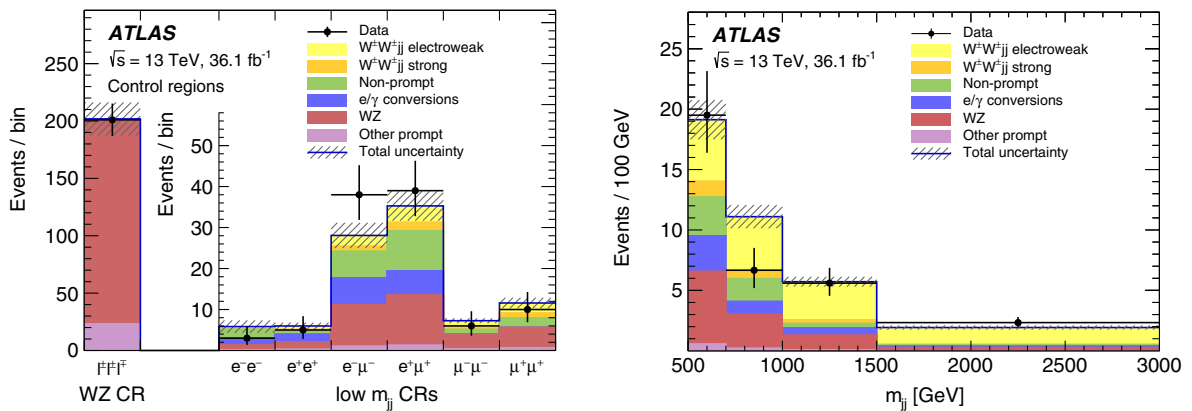


FIG. 2. Event yields for data, signal, and background in the WZ and $200 < m_{jj} < 500$ GeV control regions (left) and the m_{jj} distribution for events meeting all selection criteria for the signal region (right). Signal and background distributions are shown as predicted after the fit. The hatched band represents the statistical and systematic uncertainties of the background predictions added in quadrature. The backgrounds from $V\gamma$ production and electron charge misreconstruction are combined into the e/γ conversions category. The other prompt category combines ZZ , VVV , and $t\bar{t}V$ background contributions. The last bin on the right figure includes the overflow.

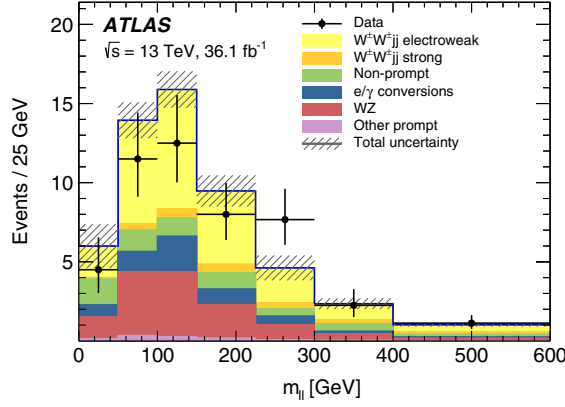


FIG. 3. The $m_{\ell\ell}$ distribution for events meeting all selection criteria for the signal region is shown as predicted after the fit. The hatched band represents the statistical and systematic uncertainties of the background prediction added in quadrature. The fitted signal strength and nuisance parameters have been propagated, with the exception of the uncertainties due to the interference and electroweak corrections for which a flat uncertainty is assigned. The backgrounds from $V\gamma$ production and electron charge misreconstruction are combined in the e/γ conversions category. The other prompt category combines ZZ , VVV , and $t\bar{t}V$ background contributions. The last bin of the distribution includes the overflow.

TABLE II. Impact of different components of systematic uncertainty on the measured fiducial cross section, without taking into account correlations. The impact of one source of systematic uncertainty is computed by first performing the fit with the corresponding nuisance parameter fixed to 1 standard deviation up or down from the value obtained in the nominal fit, then these up and down variations are symmetrized. The impacts of several sources of systematic uncertainty are added in quadrature for each component. The categorization of sources of systematic uncertainties into experimental and theory modeling correspond to those used for the measured fiducial cross section.

Source	Impact [%]
Experimental	
Electron energy scale and resolution, and efficiency	0.6
Muon momentum scale and resolution, and efficiency	1.3
Jet energy and E_T^{miss} scale and resolution	3.2
b -tagging inefficiency	2.1
Pileup modeling	1.6
Background, statistical	3.2
Background, misid. leptons	3.3
Background, charge misrec.	0.3
Background, other	1.8
Theory modeling	
$W^\pm W^\pm jj$ electroweak-strong interference	1.0
$W^\pm W^\pm jj$ electroweak, EW corrections	1.4
$W^\pm W^\pm jj$ electroweak, shower, scale, PDF & α_s	2.8
$W^\pm W^\pm jj$ strong	2.9
WZ	3.3
Luminosity	2.4

production processes that are accounted for in the modeling systematic uncertainty. Table II summarizes the impacts of different components of systematic uncertainty.

The measured fiducial cross section includes contributions from both the $W^\pm W^\pm jj$ electroweak production and its interference with the $W^\pm W^\pm jj$ strong production, estimated to be approximately 6% of the predicted fiducial cross section for $W^\pm W^\pm jj$ electroweak production. The fiducial cross section for the $W^\pm W^\pm jj$ electroweak production, without the interference effect, is predicted by SHERPA and POWHEG+PYTHIA8 to be $2.01^{+0.33}_{-0.23}$ fb and $3.08^{+0.45}_{-0.46}$ fb, respectively. The impact on the measured fiducial cross section of using POWHEG+PYTHIA8 instead of SHERPA to generate the m_{jj} signal template was tested and found to be smaller than the 3.6% signal modeling uncertainty.

In summary, the electroweak $VVjj$ production process was studied in the $W^\pm W^\pm jj$ final state using 36.1 fb^{-1} of pp collision data recorded at $\sqrt{s} = 13 \text{ TeV}$ by the ATLAS detector at the LHC. This process includes VBS diagrams that probe the mechanism of electroweak symmetry breaking. An excess of events is observed and the background-only hypothesis is rejected with a significance of 6.5σ . The fiducial cross section for $W^\pm W^\pm jj$ electroweak production is measured to be $\sigma^{\text{fid}} = 2.89^{+0.51}_{-0.48} (\text{stat})^{+0.24}_{-0.22} (\text{exp syst})^{+0.14}_{-0.16} (\text{mod syst})^{+0.08}_{-0.06} (\text{lumi}) \text{ fb}$.

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS, CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC Swedish research and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, the Canada Council, CANARIE, CRC, Compute Canada, FQRNT, and the Ontario Innovation Trust, Canada; EPLANET, ERC, ERDF, FP7, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union;

Investissements d'Avenir Labex and IDEX, ANR, Région Auvergne and Fondation Partager le Savoir, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF; BSF, GIF and Minerva, Israel; BRF, Norway; CERCA Programme Generalitat de Catalunya, Generalitat Valenciana, Spain; the Royal Society and Leverhulme Trust, United Kingdom. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [56].

- [1] M. S. Chanowitz and M. Golden, Like-Charged Gauge-Boson Pairs as a Probe of Electroweak Symmetry Breaking, *Phys. Rev. Lett.* **61**, 1053 (1988); Erratum, *Phys. Rev. Lett.* **63**, 466(E) (1989).
- [2] J. Bagger, V. Barger, K. Cheung, J. Gunion, T. Han, G. A. Ladinsky, R. Rosenfeld, and C.-P. Yuan, Strongly interacting WW system: Gold-plated modes, *Phys. Rev. D* **49**, 1246 (1994).
- [3] J. Bagger, V. Barger, K. Cheung, J. Gunion, T. Han, G. A. Ladinsky, R. Rosenfeld, and C.-P. Yuan, CERN LHC analysis of the strongly interacting WW system: Gold-plated modes, *Phys. Rev. D* **52**, 3878 (1995).
- [4] B. W. Lee, C. Quigg, and H. B. Thacker, Strength of Weak Interactions at Very High-Energies and the Higgs Boson Mass, *Phys. Rev. Lett.* **38**, 883 (1977).
- [5] B. W. Lee, C. Quigg, and H. B. Thacker, Weak interactions at very high energies: The role of the Higgs-boson mass, *Phys. Rev. D* **16**, 1519 (1977).
- [6] G. 't Hooft and M. J. G. Veltman, Regularization and renormalization of gauge fields, *Nucl. Phys.* **B44**, 189 (1972).
- [7] M. Veltman, Second threshold in weak interactions, *Acta Phys. Pol. B* **8**, 475 (1977).
- [8] B. Biedermann, A. Denner, and M. Pellen, Complete NLO corrections to W^+W^+ scattering and its irreducible background at the LHC, *J. High Energy Phys.* **10** (2017) 124.
- [9] A. Ballestrero *et al.*, Precise predictions for same-sign W-boson scattering at the LHC, *Eur. Phys. J. C* **78**, 671 (2018).
- [10] M. Szleper, The Higgs boson and the physics of WW scattering before and after Higgs discovery, [arXiv:1412.8367](https://arxiv.org/abs/1412.8367).
- [11] CMS Collaboration, Observation of Electroweak Production of Same-Sign W Boson Pairs in the Two Jet and Two Same-Sign Lepton Final State in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV, *Phys. Rev. Lett.* **120**, 081801 (2018).
- [12] ATLAS Collaboration, Evidence for Electroweak Production of $W^\pm W^\pm jj$ in pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector, *Phys. Rev. Lett.* **113**, 141803 (2014).
- [13] ATLAS Collaboration, Measurement of $W^\pm W^\pm$ vector-boson scattering and limits on anomalous quartic gauge couplings with the ATLAS detector, *Phys. Rev. D* **96**, 012007 (2017).
- [14] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, *J. Instrum.* **3**, S08003 (2008).
- [15] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z axis along the beam direction. The x axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the (x, y) plane, ϕ being the azimuthal angle around the beam direction. The rapidity is defined as $y = \frac{1}{2} \ln[(E + p_z)/(E - p_z)]$, where E is the energy of the particle and p_z is the projection of the momentum along the z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. The distance ΔR is defined as $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.
- [16] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* **70**, 823 (2010).
- [17] S. Agostinelli *et al.*, GEANT4—A simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [18] ATLAS Collaboration, Measurement of the cross-section for producing a W boson in association with a single top quark in pp collisions at $\sqrt{s} = 13$ TeV with ATLAS, *J. High Energy Phys.* **01** (2018) 063.
- [19] T. Gleisberg, S. Höche, F. Krauss, M. Schönherr, S. Schumann, F. Siegert, and J. Winter, Event generation with SHERPA 1.1, *J. High Energy Phys.* **02** (2009) 007.
- [20] T. Gleisberg and S. Höche, Comix, a new matrix element generator, *J. High Energy Phys.* **12** (2008) 039.
- [21] S. Schumann and F. Krauss, A Parton shower algorithm based on Catani-Seymour dipole factorisation, *J. High Energy Phys.* **03** (2008) 038.
- [22] S. Höche, F. Krauss, S. Schumann, and F. Siegert, QCD matrix elements and truncated showers, *J. High Energy Phys.* **05** (2009) 053.
- [23] R. D. Ball *et al.*, Parton distributions for the LHC Run II, *J. High Energy Phys.* **04** (2015) 040.
- [24] ATLAS Collaboration, Modelling of the vector boson scattering process $pp \rightarrow W^\pm W^\pm jj$ in Monte Carlo generators in ATLAS, CERN Report No. ATL-PHYS-PUB-2019-004, 2019, <https://cds.cern.ch/record/2655303>.
- [25] ATLAS Collaboration, Multi-Boson simulation for 13 TeV ATLAS analyses, CERN Report No. ATL-PHYS-PUB-2017-005, 2017, <http://cds.cern.ch/record/2261933>.
- [26] S. Höche, F. Krauss, M. Schönherr, and F. Siegert, QCD matrix elements + parton showers: The NLO case, *J. High Energy Phys.* **04** (2013) 027.
- [27] M. Schönherr and F. Krauss, Soft photon radiation in particle decays in SHERPA, *J. High Energy Phys.* **12** (2008) 018.
- [28] B. Jäger and G. Zanderighi, NLO corrections to electroweak and QCD production of W^+W^+ plus two jets in the POWHEG BOX, *J. High Energy Phys.* **11** (2011) 055.
- [29] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* **11** (2004) 040.
- [30] S. Frixione, P. Nason, and C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, *J. High Energy Phys.* **11** (2007) 070.
- [31] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower

- Monte Carlo programs: the POWHEG BOX, *J. High Energy Phys.* **06** (2010) 043.
- [32] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [33] B. Jäger, C. Oleari, and D. Zeppenfeld, Next-to-leading order QCD corrections to W^+W^+jj and W^-W^-jj production via weak-boson fusion, *Phys. Rev. D* **80**, 034022 (2009).
- [34] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C.-P. Yuan, New parton distributions for collider physics, *Phys. Rev. D* **82**, 074024 (2010).
- [35] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* **07** (2014) 079.
- [36] M. Cacciari, G. P. Salam, and G. Soyez, The anti- k_t jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [37] S. Dulat, T.-J. Hou, J. Gao, M. Guzzi, J. Huston, P. Nadolsky, J. Pumplin, C. Schmidt, D. Stump, and C.-P. Yuan, New parton distribution functions from a global analysis of quantum chromodynamics, *Phys. Rev. D* **93**, 033006 (2016).
- [38] L. A. Harland-Lang, A. D. Martin, P. Motylinski, and R. S. Thorne, Parton distributions in the LHC era: MMHT 2014 PDFs, *Eur. Phys. J. C* **75**, 204 (2015).
- [39] J. Butterworth *et al.*, PDF4LHC recommendations for LHC Run II, *J. Phys. G* **43**, 023001 (2016).
- [40] M. Bahr *et al.*, Herwig++ physics and manual, *Eur. Phys. J. C* **58**, 639 (2008).
- [41] J. Bellm *et al.*, Herwig 7.0/Herwig++ 3.0 release note, *Eur. Phys. J. C* **76**, 196 (2016).
- [42] ATLAS Collaboration, Electron reconstruction and identification in the ATLAS experiment using the 2015 and 2016 LHC proton-proton collision data at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* **79**, 639 (2019).
- [43] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton-proton collision data at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* **76**, 292 (2016).
- [44] ATLAS Collaboration, Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1, *Eur. Phys. J. C* **77**, 490 (2017).
- [45] ATLAS Collaboration, Jet energy scale measurements and their systematic uncertainties in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Rev. D* **96**, 072002 (2017).
- [46] ATLAS Collaboration, Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector, *Eur. Phys. J. C* **76**, 581 (2016).
- [47] ATLAS Collaboration, Measurements of b-jet tagging efficiency with the ATLAS detector using $t\bar{t}$ events at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* **08** (2018) 089.
- [48] ATLAS Collaboration, Performance of missing transverse momentum reconstruction with the ATLAS detector using proton-proton collisions at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* **78**, 903 (2018).
- [49] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* **77**, 317 (2017).
- [50] ATLAS Collaboration, Multi-Boson simulation for 13 TeV ATLAS analyses, CERN Report No. ATL-PHYS-PUB-2016-002, 2016, <https://cds.cern.ch/record/2119986>.
- [51] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs cross sections: 4. Deciphering the Nature of the Higgs sector, [arXiv:1610.07922](https://arxiv.org/abs/1610.07922).
- [52] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC, CERN Report No. ATLAS-CONF-2019-021, 2019, <https://cds.cern.ch/record/2677054>.
- [53] B. Biedermann, A. Denner, and M. Pellen, Large Electroweak Corrections to Vector-Boson Scattering at the Large Hadron Collider, *Phys. Rev. Lett.* **118**, 261801 (2017).
- [54] M. Chiesa, A. Denner, J.-N. Lang, and M. Pellen, An event generator for same-sign W-boson scattering at the LHC including electroweak corrections, *Eur. Phys. J. C* **79**, 788 (2019).
- [55] K. Cranmer, G. Lewis, L. Moneta, A. Shibata, and W. Verkerke, HistFactory: A tool for creating statistical models for use with RooFit and RooStats, 2012, [http://cds.cern.ch/record/1456844/](https://cds.cern.ch/record/1456844/).
- [56] ATLAS Collaboration, ATLAS computing acknowledgements, CERN Report No. ATL-GEN-PUB-2016-002, <https://cds.cern.ch/record/2202407>.

M. Aaboud,^{35d} G. Aad,¹⁰⁰ B. Abbott,¹²⁷ O. Abidinov,^{13,a} B. Abeloos,¹³¹ D. K. Abhayasinghe,⁹² S. H. Abidi,¹⁶⁶ O. S. AbouZeid,⁴⁰ N. L. Abraham,¹⁵⁵ H. Abramowicz,¹⁶⁰ H. Abreu,¹⁵⁹ Y. Abulaiti,⁶ B. S. Acharya,^{65a,65b,b} S. Adachi,¹⁶² L. Adam,⁹⁸ C. Adam Bourdarios,¹³¹ L. Adamczyk,^{82a} J. Adelman,¹²⁰ M. Adersberger,¹¹³ A. Adiguzel,^{12c} T. Adye,¹⁴³ A. A. Affolder,¹⁴⁵ Y. Afik,¹⁵⁹ C. Agheorghiesei,^{27c} J. A. Aguilar-Saavedra,^{139f,139a} F. Ahmadov,^{78,c} G. Aielli,^{72a,72b} S. Akatsuka,⁸⁴ T. P. A. Åkesson,⁹⁵ E. Akilli,⁵³ A. V. Akimov,¹⁰⁹ G. L. Alberghi,^{23b,23a} J. Albert,¹⁷⁵ P. Albicocco,⁵⁰ M. J. Alconada Verzini,⁸⁷ S. Alderweireldt,¹¹⁸ M. Aleksa,³⁶ I. N. Aleksandrov,⁷⁸ C. Alexa,^{27b} T. Alexopoulos,¹⁰ M. Alhroob,¹²⁷ B. Ali,¹⁴¹ G. Alimonti,^{67a} J. Alison,³⁷ S. P. Alkire,¹⁴⁷ C. Allaire,¹³¹ B. M. M. Allbrooke,¹⁵⁵ B. W. Allen,¹³⁰ P. P. Allport,²¹ A. Aloisio,^{68a,68b} A. Alonso,⁴⁰ F. Alonso,⁸⁷ C. Alpigiani,¹⁴⁷ A. A. Alshehri,⁵⁶ M. I. Alstaty,¹⁰⁰ B. Alvarez Gonzalez,³⁶ D. Álvarez Piqueras,¹⁷³ M. G. Alvigi,^{68a,68b} B. T. Amadio,¹⁸ Y. Amaral Coutinho,^{79b} A. Ambler,¹⁰² L. Ambroz,¹³⁴ C. Amelung,²⁶ D. Amidei,¹⁰⁴ S. P. Amor Dos Santos,^{139a,139c} S. Amoroso,⁴⁵ C. S. Amrouche,⁵³ C. Anastopoulos,¹⁴⁸ L. S. Ancu,⁵³ N. Andari,¹⁴⁴ T. Andeen,¹¹ C. F. Anders,^{60b} J. K. Anders,²⁰ K. J. Anderson,³⁷

- A. Andreazza,^{67a,67b} V. Andrei,^{60a} C. R. Anelli,¹⁷⁵ S. Angelidakis,³⁸ I. Angelozzi,¹¹⁹ A. Angerami,³⁹ A. V. Anisenkov,^{121b,121a}
 A. Annovi,^{70a} C. Antel,^{60a} M. T. Anthony,¹⁴⁸ M. Antonelli,⁵⁰ D. J. A. Antrim,¹⁷⁰ F. Anulli,^{71a} M. Aoki,⁸⁰
 J. A. Aparisi Pozo,¹⁷³ L. Aperio Bella,³⁶ G. Arabidze,¹⁰⁵ J. P. Araque,^{139a} V. Araujo Ferraz,^{79b} R. Araujo Pereira,^{79b}
 A. T. H. Arce,⁴⁸ R. E. Ardell,⁹² F. A. Arduh,⁸⁷ J-F. Arguin,¹⁰⁸ S. Argyropoulos,⁷⁶ A. J. Armbruster,³⁶ L. J. Armitage,⁹¹
 A. Armstrong,¹⁷⁰ O. Arnaez,¹⁶⁶ H. Arnold,¹¹⁹ M. Arratia,³² O. Arslan,²⁴ A. Artamonov,^{110,a} G. Artoni,¹³⁴ S. Artz,⁹⁸
 S. Asai,¹⁶² N. Asbah,⁵⁸ E. M. Asimakopoulou,¹⁷¹ L. Asquith,¹⁵⁵ K. Assamagan,²⁹ R. Astalos,^{28a} R. J. Atkin,^{33a}
 M. Atkinson,¹⁷² N. B. Atlay,¹⁵⁰ K. Augsten,¹⁴¹ G. Avolio,³⁶ R. Avramidou,^{59a} M. K. Ayoub,^{15a} A. M. Azoulay,^{167b}
 G. Azuelos,^{108,d} A. E. Baas,^{60a} M. J. Baca,²¹ H. Bachacou,¹⁴⁴ K. Bachas,^{66a,66b} M. Backes,¹³⁴ P. Bagnaia,^{71a,71b}
 M. Bahmani,⁸³ H. Bahrasmehani,¹⁵¹ A. J. Bailey,¹⁷³ J. T. Baines,¹⁴³ M. Bajic,⁴⁰ C. Bakalis,¹⁰ O. K. Baker,¹⁸² P. J. Bakker,¹¹⁹
 D. Bakshi Gupta,⁸ S. Balaji,¹⁵⁶ E. M. Baldin,^{121b,121a} P. Balek,¹⁷⁹ F. Balli,¹⁴⁴ W. K. Balunas,¹³⁶ J. Balz,⁹⁸ E. Banas,⁸³
 A. Bandyopadhyay,²⁴ Sw. Banerjee,^{180,e} A. A. E. Bannoura,¹⁸¹ L. Barak,¹⁶⁰ W. M. Barbe,³⁸ E. L. Barberio,¹⁰³
 D. Barberis,^{54b,54a} M. Barbero,¹⁰⁰ T. Barillari,¹¹⁴ M-S. Barisits,³⁶ J. Barkeloo,¹³⁰ T. Barklow,¹⁵² R. Barnea,¹⁵⁹ S. L. Barnes,^{59c}
 B. M. Barnett,¹⁴³ R. M. Barnett,¹⁸ Z. Barnovska-Blenessy,^{59a} A. Baroncelli,^{73a} G. Barone,²⁹ A. J. Barr,¹³⁴
 L. Barranco Navarro,¹⁷³ F. Barreiro,⁹⁷ J. Barreiro Guimarães da Costa,^{15a} R. Bartoldus,¹⁵² A. E. Barton,⁸⁸ P. Bartos,^{28a}
 A. Basalaez,¹³⁷ A. Bassalat,^{131,f} R. L. Bates,⁵⁶ S. J. Batista,¹⁶⁶ S. Batlamous,^{35e} J. R. Batley,³² M. Battaglia,¹⁴⁵
 M. Bause,^{71a,71b} F. Bauer,¹⁴⁴ K. T. Bauer,¹⁷⁰ H. S. Bawa,^{31,g} J. B. Beacham,¹²⁵ T. Beau,¹³⁵ P. H. Beauchemin,¹⁶⁹ P. Bechtle,²⁴
 H. C. Beck,⁵² H. P. Beck,^{20,h} K. Becker,⁵¹ M. Becker,⁹⁸ C. Becot,⁴⁵ A. Beddall,^{12d} A. J. Beddall,^{12a} V. A. Bednyakov,⁷⁸
 M. Bedognetti,¹¹⁹ C. P. Bee,¹⁵⁴ T. A. Beermann,⁷⁵ M. Begalli,^{79b} M. Begel,²⁹ A. Behera,¹⁵⁴ J. K. Behr,⁴⁵ A. S. Bell,⁹³
 G. Bella,¹⁶⁰ L. Bellagamba,^{23b} A. Bellerive,³⁴ M. Bellomo,¹⁵⁹ P. Bellos,⁹ K. Belotskiy,¹¹¹ N. L. Belyaev,¹¹¹ O. Benary,^{160,a}
 D. Benchechrone,^{35a} M. Bender,¹¹³ N. Benekos,¹⁰ Y. Benhammou,¹⁶⁰ E. Benhar Noccioli,¹⁸² J. Benitez,⁷⁶ D. P. Benjamin,⁴⁸
 M. Benoit,⁵³ J. R. Bensinger,²⁶ S. Bentvelsen,¹¹⁹ L. Beresford,¹³⁴ M. Beretta,⁵⁰ D. Berge,⁴⁵ E. Bergeas Kuutmann,¹⁷¹
 N. Berger,⁵ B. Bergmann,¹⁴¹ L. J. Bergsten,²⁶ J. Beringer,¹⁸ S. Berlendis,⁷ N. R. Bernard,¹⁰¹ G. Bernardi,¹³⁵ C. Bernius,¹⁵²
 F. U. Bernlochner,²⁴ T. Berry,⁹² P. Berta,⁹⁸ C. Bertella,^{15a} G. Bertoli,^{44a,44b} I. A. Bertram,⁸⁸ G. J. Besjes,⁴⁰
 O. Bessidskaia Bylund,¹⁸¹ M. Bessner,⁴⁵ N. Besson,¹⁴⁴ A. Bethani,⁹⁹ S. Bethke,¹¹⁴ A. Betti,²⁴ A. J. Bevan,⁹¹ J. Beyer,¹¹⁴
 R. Bi,¹³⁸ R. M. Bianchi,¹³⁸ O. Biebel,¹¹³ D. Biedermann,¹⁹ R. Bielski,³⁶ K. Bierwagen,⁹⁸ N. V. Biesuz,^{70a,70b} M. Biglietti,^{73a}
 T. R. V. Billoud,¹⁰⁸ M. Bindi,⁵² A. Bingul,^{12d} C. Bini,^{71a,71b} S. Biondi,^{23b,23a} M. Birman,¹⁷⁹ T. Bisanz,⁵² J. P. Biswal,¹⁶⁰
 C. Bittrich,⁴⁷ D. M. Bjergaard,⁴⁸ J. E. Black,¹⁵² K. M. Black,²⁵ T. Blazek,^{28a} I. Bloch,⁴⁵ C. Blocker,²⁶ A. Blue,⁵⁶
 U. Blumenschein,⁹¹ S. Blunier,^{146a} G. J. Bobbink,¹¹⁹ V. S. Bobrovnikov,^{121b,121a} S. S. Bocchetta,⁹⁵ A. Bocci,⁴⁸ D. Boerner,¹⁸¹
 D. Bogavac,¹¹³ A. G. Bogdanchikov,^{121b,121a} C. Bohm,^{44a} V. Boisvert,⁹² P. Bokan,^{171,52} T. Bold,^{82a} A. S. Boldyrev,¹¹²
 A. E. Bolz,^{60b} M. Bomben,¹³⁵ M. Bona,⁹¹ J. S. Bonilla,¹³⁰ M. Boonekamp,¹⁴⁴ A. Borisov,¹²² G. Borissov,⁸⁸ J. Bortfeldt,³⁶
 D. Bortoletto,¹³⁴ V. Bortolotto,^{72a,72b} D. Boscherini,^{23b} M. Bosman,¹⁴ J. D. Bossio Sola,³⁰ K. Bouaouda,^{35a} J. Boudreau,¹³⁸
 E. V. Bouhova-Thacker,⁸⁸ D. Boumediene,³⁸ S. K. Boutle,⁵⁶ A. Boveia,¹²⁵ J. Boyd,³⁶ D. Boye,^{33b} I. R. Boyko,⁷⁸
 A. J. Bozson,⁹² J. Bracinik,²¹ N. Brahimi,¹⁰⁰ A. Brandt,⁸ G. Brandt,¹⁸¹ O. Brandt,^{60a} F. Braren,⁴⁵ U. Bratzler,¹⁶³ B. Brau,¹⁰¹
 J. E. Brau,¹³⁰ W. D. Breaden Madden,⁵⁶ K. Brendlinger,⁴⁵ L. Brenner,⁴⁵ R. Brenner,¹⁷¹ S. Bressler,¹⁷⁹ B. Brickwedde,⁹⁸
 D. L. Briglin,²¹ D. Britton,⁵⁶ D. Britzger,¹¹⁴ I. Brock,²⁴ R. Brock,¹⁰⁵ G. Brooijmans,³⁹ T. Brooks,⁹² W. K. Brooks,^{146b}
 E. Brost,¹²⁰ J. H. Broughton,²¹ P. A. Bruckman de Renstrom,⁸³ D. Bruncko,^{28b} A. Bruni,^{23b} G. Bruni,^{23b} L. S. Bruni,¹¹⁹
 S. Bruno,^{72a,72b} B. H. Brunt,³² M. Bruschi,^{23b} N. Bruscino,¹³⁸ P. Bryant,³⁷ L. Bryngemark,⁴⁵ T. Buanes,¹⁷ Q. Buat,³⁶
 P. Buchholz,¹⁵⁰ A. G. Buckley,⁵⁶ I. A. Budagov,⁷⁸ M. K. Bugge,¹³³ F. Bühner,⁵¹ O. Bulekov,¹¹¹ D. Bullock,⁸ T. J. Burch,¹²⁰
 S. Burdin,⁸⁹ C. D. Burgard,¹¹⁹ A. M. Burger,⁵ B. Burghgrave,¹²⁰ K. Burka,⁸³ S. Burke,¹⁴³ I. Burmeister,⁴⁶ J. T. P. Burr,¹³⁴
 V. Büscher,⁹⁸ E. Buschmann,⁵² P. J. Bussey,⁵⁶ J. M. Butler,²⁵ C. M. Buttar,⁵⁶ J. M. Butterworth,⁹³ P. Butti,³⁶ W. Buttinger,³⁶
 A. Buzatu,¹⁵⁷ A. R. Buzykaev,^{121b,121a} G. Cabras,^{23b,23a} S. Cabrera Urbán,¹⁷³ D. Caforio,¹⁴¹ H. Cai,¹⁷² V. M. M. Cairo,²
 O. Cakir,^{4a} N. Calace,⁵³ P. Calafiura,¹⁸ A. Calandri,¹⁰⁰ G. Calderini,¹³⁵ P. Calfayan,⁶⁴ G. Callea,^{41b,41a} L. P. Caloba,^{79b}
 S. Calvente Lopez,⁹⁷ D. Calvet,³⁸ S. Calvet,³⁸ T. P. Calvet,¹⁵⁴ M. Calvetti,^{70a,70b} R. Camacho Toro,¹³⁵ S. Camarda,³⁶
 D. Camarero Munoz,⁹⁷ P. Camarri,^{72a,72b} D. Cameron,¹³³ R. Caminal Armadans,¹⁰¹ C. Camincher,³⁶ S. Campana,³⁶
 M. Campanelli,⁹³ A. Camplani,⁴⁰ A. Campoverde,¹⁵⁰ V. Canale,^{68a,68b} M. Cano Bret,^{59c} J. Cantero,¹²⁸ T. Cao,¹⁶⁰ Y. Cao,¹⁷²
 M. D. M. Capeans Garrido,³⁶ I. Caprini,^{27b} M. Caprini,^{27b} M. Capua,^{41b,41a} R. M. Carbone,³⁹ R. Cardarelli,^{72a}
 F. C. Cardillo,¹⁴⁸ I. Carli,¹⁴² T. Carli,³⁶ G. Carlino,^{68a} B. T. Carlson,¹³⁸ L. Carminati,^{67a,67b} R. M. D. Carney,^{44a,44b}
 S. Caron,¹¹⁸ E. Carquin,^{146b} S. Carrá,^{67a,67b} G. D. Carrillo-Montoya,³⁶ D. Casadei,^{33b} M. P. Casado,¹⁴ⁱ A. F. Casha,¹⁶⁶
 D. W. Casper,¹⁷⁰ R. Castelijns,¹¹⁹ F. L. Castillo,¹⁷³ V. Castillo Gimenez,¹⁷³ N. F. Castro,^{139a,139e} A. Catinaccio,³⁶

- J. R. Catmore,¹³³ A. Cattai,³⁶ J. Caudron,²⁴ V. Cavaliere,²⁹ E. Cavallaro,¹⁴ D. Cavalli,^{67a} M. Cavalli-Sforza,¹⁴
 V. Cavasinni,^{70a,70b} E. Celebi,^{12b} F. Ceradini,^{73a,73b} L. Cerda Alberich,¹⁷³ A. S. Cerqueira,^{79a} A. Cerri,¹⁵⁵ L. Cerrito,^{72a,72b}
 F. Cerutti,¹⁸ A. Cervelli,^{23b,23a} S. A. Cetin,^{12b} A. Chafaq,^{35a} D. Chakraborty,¹²⁰ S. K. Chan,⁵⁸ W. S. Chan,¹¹⁹ Y. L. Chan,^{62a}
 J. D. Chapman,³² B. Chargeishvili,^{158b} D. G. Charlton,²¹ C. C. Chau,³⁴ C. A. Chavez Barajas,¹⁵⁵ S. Che,¹²⁵
 A. Chegwidden,¹⁰⁵ S. Chekanov,⁶ S. V. Chekulaev,^{167a} G. A. Chelkov,^{78,j} M. A. Chelstowska,³⁶ C. Chen,^{59a} C. H. Chen,⁷⁷
 H. Chen,²⁹ J. Chen,^{59a} J. Chen,³⁹ S. Chen,¹³⁶ S. J. Chen,^{15c} X. Chen,^{15b,k} Y. Chen,⁸¹ Y.-H. Chen,⁴⁵ H. C. Cheng,¹⁰⁴
 H. J. Cheng,^{15a,15d} A. Cheplakov,⁷⁸ E. Cheremushkina,¹²² R. Cherkaoui El Moursli,^{35e} E. Cheu,⁷ K. Cheung,⁶³
 L. Chevalier,¹⁴⁴ V. Chiarella,⁵⁰ G. Chiarelli,^{70a} G. Chiodini,^{66a} A. S. Chisholm,^{36,21} A. Chitan,^{27b} I. Chiu,¹⁶² Y. H. Chiu,¹⁷⁵
 M. V. Chizhov,⁷⁸ K. Choi,⁶⁴ A. R. Chomont,¹³¹ S. Chouridou,¹⁶¹ Y. S. Chow,¹¹⁹ V. Christodoulou,⁹³ M. C. Chu,^{62a}
 J. Chudoba,¹⁴⁰ A. J. Chuinard,¹⁰² J. J. Chwastowski,⁸³ L. Chytka,¹²⁹ D. Cinca,⁴⁶ V. Cindro,⁹⁰ I. A. Cioară,²⁴ A. Ciocio,¹⁸
 F. Ciotto,^{68a,68b} Z. H. Citron,¹⁷⁹ M. Citterio,^{67a} A. Clark,⁵³ M. R. Clark,³⁹ P. J. Clark,⁴⁹ C. Clement,^{44a,44b} Y. Coadou,¹⁰⁰
 M. Cobal,^{65a,65c} A. Coccaro,^{54b} J. Cochran,⁷⁷ H. Cohen,¹⁶⁰ A. E. C. Coimbra,¹⁷⁹ L. Colasurdo,¹¹⁸ B. Cole,³⁹ A. P. Colijn,¹¹⁹
 J. Collot,⁵⁷ P. Conde Muiño,^{139a} E. Coniavitis,⁵¹ S. H. Connell,^{33b} I. A. Connelly,⁹⁹ S. Constantinescu,^{27b} F. Conventi,^{68a,1}
 A. M. Cooper-Sarkar,¹³⁴ F. Cormier,¹⁷⁴ K. J. R. Cormier,¹⁶⁶ L. D. Corpe,⁹³ M. Corradi,^{71a,71b} E. E. Corrigan,⁹⁵
 F. Corriveau,^{102,m} A. Cortes-Gonzalez,³⁶ M. J. Costa,¹⁷³ F. Costanza,⁵ D. Costanzo,¹⁴⁸ G. Cottin,³² G. Cowan,⁹² B. E. Cox,⁹⁹
 J. Crane,⁹⁹ K. Cranmer,¹²³ S. J. Crawley,⁵⁶ R. A. Creager,¹³⁶ G. Cree,³⁴ S. Crépe-Renaudin,⁵⁷ F. Crescioli,¹³⁵
 M. Cristinziani,²⁴ V. Croft,¹²³ G. Crosetti,^{41b,41a} A. Cueto,⁹⁷ T. Cuhadar Donszelmann,¹⁴⁸ A. R. Cukierman,¹⁵²
 S. Czekierda,⁸³ P. Czodrowski,³⁶ M. J. Da Cunha Sargedas De Sousa,^{59b} C. Da Via,⁹⁹ W. Dabrowski,^{82a} T. Dado,^{28a,n}
 S. Dahbi,^{35e} T. Dai,¹⁰⁴ F. Dallaire,¹⁰⁸ C. Dallapiccola,¹⁰¹ M. Dam,⁴⁰ G. D'amen,^{23b,23a} J. Damp,⁹⁸ J. R. Dandoy,¹³⁶
 M. F. Daneri,³⁰ N. P. Dang,¹⁸⁰ N. D. Dann,⁹⁹ M. Danninger,¹⁷⁴ V. Dao,³⁶ G. Darbo,^{54b} S. Darmora,⁸ O. Dartsis,⁵
 A. Dattagupta,¹³⁰ T. Daubney,⁴⁵ S. D'Auria,^{67a,67b} W. Davey,²⁴ C. David,⁴⁵ T. Davidek,¹⁴² D. R. Davis,⁴⁸ E. Dawe,¹⁰³
 I. Dawson,¹⁴⁸ K. De,⁸ R. De Asmundis,^{68a} A. De Benedetti,¹²⁷ M. De Beurs,¹¹⁹ S. De Castro,^{23b,23a} S. De Cecco,^{71a,71b}
 N. De Groot,¹¹⁸ P. de Jong,¹¹⁹ H. De la Torre,¹⁰⁵ F. De Lorenzi,⁷⁷ A. De Maria,^{70a,70b} D. De Pedis,^{71a} A. De Salvo,^{71a}
 U. De Sanctis,^{72a,72b} M. De Santis,^{72a,72b} A. De Santo,¹⁵⁵ K. De Vasconcelos Corga,¹⁰⁰ J. B. De Vivie De Regie,¹³¹
 C. Debenedetti,¹⁴⁵ D. V. Dedovich,⁷⁸ N. Dehghanian,³ A. M. Deiana,¹⁰⁴ M. Del Gaudio,^{41b,41a} J. Del Peso,⁹⁷
 Y. Delabat Diaz,⁴⁵ D. Delgove,¹³¹ F. Deliot,¹⁴⁴ C. M. Delitzsch,⁷ M. Della Pietra,^{68a,68b} D. Della Volpe,⁵³ A. Dell'Acqua,³⁶
 L. Dell'Asta,²⁵ M. Delmastro,⁵ C. Delporte,¹³¹ P. A. Delsart,⁵⁷ D. A. DeMarco,¹⁶⁶ S. Demers,¹⁸² M. Demichev,⁷⁸
 S. P. Denisov,¹²² D. Denysiuk,¹¹⁹ L. D'Eramo,¹³⁵ D. Derendarz,⁸³ J. E. Derkaoui,^{35d} F. Derue,¹³⁵ P. Dervan,⁸⁹ K. Desch,²⁴
 C. Deterre,⁴⁵ K. Dette,¹⁶⁶ M. R. Devesa,³⁰ P. O. Deviveiros,³⁶ A. Dewhurst,¹⁴³ S. Dhaliwal,²⁶ F. A. Di Bello,⁵³
 A. Di Ciaccio,^{72a,72b} L. Di Ciaccio,⁵ W. K. Di Clemente,¹³⁶ C. Di Donato,^{68a,68b} A. Di Girolamo,³⁶ G. Di Gregorio,^{70a,70b}
 B. Di Micco,^{73a,73b} R. Di Nardo,¹⁰¹ K. F. Di Petrillo,⁵⁸ R. Di Sipio,¹⁶⁶ D. Di Valentino,³⁴ C. Diaconu,¹⁰⁰ M. Diamond,¹⁶⁶
 F. A. Dias,⁴⁰ T. Dias Do Vale,^{139a} M. A. Diaz,^{146a} J. Dickinson,¹⁸ E. B. Diehl,¹⁰⁴ J. Dietrich,¹⁹ S. Díez Cornell,⁴⁵
 A. Dimitrievska,¹⁸ J. Dingfelder,²⁴ F. Dittus,³⁶ F. Djama,¹⁰⁰ T. Djobava,^{158b} J. I. Djuvsland,^{60a} M. A. B. Do Vale,^{79c}
 M. Dobre,^{27b} D. Dodsworth,²⁶ C. Doglioni,⁹⁵ J. Dolejsi,¹⁴² Z. Dolezal,¹⁴² M. Donadelli,^{79d} J. Donini,³⁸ A. D'onofrio,⁹¹
 M. D'Onofrio,⁸⁹ J. Dopke,¹⁴³ A. Doria,^{68a} M. T. Dova,⁸⁷ A. T. Doyle,⁵⁶ E. Drechsler,⁵² E. Dreyer,¹⁵¹ T. Dreyer,⁵² Y. Du,^{59b}
 F. Dubinin,¹⁰⁹ M. Dubovsky,^{28a} A. Dubreuil,⁵³ E. Duchovni,¹⁷⁹ G. Duckeck,¹¹³ A. Ducourthial,¹³⁵ O. A. Ducu,^{108,o}
 D. Duda,¹¹⁴ A. Dudarev,³⁶ A. C. Dudder,⁹⁸ E. M. Duffield,¹⁸ L. Duflost,¹³¹ M. Dührssen,³⁶ C. Dülsen,¹⁸¹ M. Dumancic,¹⁷⁹
 A. E. Dumitriu,^{27b,p} A. K. Duncan,⁵⁶ M. Dunford,^{60a} A. Duperrin,¹⁰⁰ H. Duran Yildiz,^{4a} M. Düren,⁵⁵ A. Durglishvili,^{158b}
 D. Duschinger,⁴⁷ B. Dutta,⁴⁵ D. Duvnjak,¹ M. Dyndal,⁴⁵ S. Dysch,⁹⁹ B. S. Dziedzic,⁸³ C. Eckardt,⁴⁵ K. M. Ecker,¹¹⁴
 R. C. Edgar,¹⁰⁴ T. Eifert,³⁶ G. Eigen,¹⁷ K. Einsweiler,¹⁸ T. Ekelof,¹⁷¹ M. El Kacimi,^{35c} R. El Kosseifi,¹⁰⁰ V. Ellajosyula,¹⁰⁰
 M. Ellert,¹⁷¹ F. Ellinghaus,¹⁸¹ A. A. Elliot,⁹¹ N. Ellis,³⁶ J. Elmsheuser,²⁹ M. Elsing,³⁶ D. Emeliyanov,¹⁴³ A. Emerman,³⁹
 Y. Enari,¹⁶² J. S. Ennis,¹⁷⁷ M. B. Epland,⁴⁸ J. Erdmann,⁴⁶ A. Ereditato,²⁰ S. Errede,¹⁷² M. Escalier,¹³¹ C. Escobar,¹⁷³
 O. Estrada Pastor,¹⁷³ A. I. Etiennevire,¹⁴⁴ E. Etzion,¹⁶⁰ H. Evans,⁶⁴ A. Ezhilov,¹³⁷ M. Ezzi,^{35e} F. Fabbri,⁵⁶ L. Fabbri,^{23b,23a}
 V. Fabiani,¹¹⁸ G. Facini,⁹³ R. M. Faisca Rodrigues Pereira,^{139a} R. M. Fakhruddinov,¹²² S. Falciano,^{71a} P. J. Falke,⁵ S. Falke,⁵
 J. Faltova,¹⁴² Y. Fang,^{15a} M. Fanti,^{67a,67b} A. Farbin,⁸ A. Farilla,^{73a} E. M. Farina,^{69a,69b} T. Farooque,¹⁰⁵ S. Farrell,¹⁸
 S. M. Farrington,¹⁷⁷ P. Farthouat,³⁶ F. Fassi,^{35e} P. Fassnacht,³⁶ D. Fassouliotis,⁹ M. Fauci Giannelli,⁴⁹ A. Favareto,^{54b,54a}
 W. J. Fawcett,³² L. Fayard,¹³¹ O. L. Fedin,^{137,q} W. Fedorko,¹⁷⁴ M. Feickert,⁴² S. Feigl,¹³³ L. Feligioni,¹⁰⁰ C. Feng,^{59b}
 E. J. Feng,³⁶ M. Feng,⁴⁸ M. J. Fenton,⁵⁶ A. B. Fenyuk,¹²² L. Feremenga,⁸ J. Ferrando,⁴⁵ A. Ferrari,¹⁷¹ P. Ferrari,¹¹⁹
 R. Ferrari,^{69a} D. E. Ferreira de Lima,^{60b} A. Ferrer,¹⁷³ D. Ferrere,⁵³ C. Ferretti,¹⁰⁴ F. Fiedler,⁹⁸ A. Filipčič,⁹⁰ F. Filthaut,¹¹⁸

- K. D. Finelli,²⁵ M. C. N. Fiolhais,^{139a,139c,r} L. Fiorini,¹⁷³ C. Fischer,¹⁴ W. C. Fisher,¹⁰⁵ N. Flaschel,⁴⁵ I. Fleck,¹⁵⁰
 P. Fleischmann,¹⁰⁴ R. R. M. Fletcher,¹³⁶ T. Flick,¹⁸¹ B. M. Flierl,¹¹³ L. F. Flores,¹³⁶ L. R. Flores Castillo,^{62a}
 F. M. Follega,^{74a,74b} N. Fomin,¹⁷ G. T. Forcolin,^{74a,74b} A. Formica,¹⁴⁴ F. A. Förster,¹⁴ A. C. Forti,⁹⁹ A. G. Foster,²¹
 D. Fournier,¹³¹ H. Fox,⁸⁸ S. Fracchia,¹⁴⁸ P. Francavilla,^{70a,70b} M. Franchini,^{23b,23a} S. Franchino,^{60a} D. Francis,³⁶
 L. Franconi,¹⁴⁵ M. Franklin,⁵⁸ M. Frate,¹⁷⁰ M. Fraternali,^{69a,69b} A. N. Fray,⁹¹ D. Freeborn,⁹³ S. M. Fressard-Batraneanu,³⁶
 B. Freund,¹⁰⁸ W. S. Freund,^{79b} E. M. Freundlich,⁴⁶ D. C. Frizzell,¹²⁷ D. Froidevaux,³⁶ J. A. Frost,¹³⁴ C. Fukunaga,¹⁶³
 E. Fullana Torregrosa,¹⁷³ T. Fusayasu,¹¹⁵ J. Fuster,¹⁷³ O. Gabizon,¹⁵⁹ A. Gabrielli,^{23b,23a} A. Gabrielli,¹⁸ G. P. Gach,^{82a}
 S. Gadatsch,⁵³ P. Gadow,¹¹⁴ G. Gagliardi,^{54b,54a} L. G. Gagnon,¹⁰⁸ C. Galea,^{27b} B. Galhardo,^{139a,139c} E. J. Gallas,¹³⁴
 B. J. Gallop,¹⁴³ P. Gallus,¹⁴¹ G. Galster,⁴⁰ R. Gamboa Goni,⁹¹ K. K. Gan,¹²⁵ S. Ganguly,¹⁷⁹ J. Gao,^{59a} Y. Gao,⁸⁹ Y. S. Gao,^{31,g}
 C. García,¹⁷³ J. E. García Navarro,¹⁷³ J. A. García Pascual,^{15a} M. Garcia-Sciveres,¹⁸ R. W. Gardner,³⁷ N. Garelli,¹⁵²
 V. Garonne,¹³³ K. Gasnikova,⁴⁵ A. Gaudiello,^{54b,54a} G. Gaudio,^{69a} I. L. Gavrilenko,¹⁰⁹ A. Gavrilyuk,¹¹⁰ C. Gay,¹⁷⁴
 G. Gaycken,²⁴ E. N. Gazis,¹⁰ C. N. P. Gee,¹⁴³ J. Geisen,⁵² M. Geisen,⁹⁸ M. P. Geisler,^{60a} K. Gellerstedt,^{44a,44b} C. Gemme,^{54b}
 M. H. Genest,⁵⁷ C. Geng,¹⁰⁴ S. Gentile,^{71a,71b} S. George,⁹² D. Gerbaudo,¹⁴ G. Gessner,⁴⁶ S. Ghasemi,¹⁵⁰
 M. Ghasemi Bostanabad,¹⁷⁵ M. Ghneimat,²⁴ B. Giacobbe,^{23b} S. Giagu,^{71a,71b} N. Giangiacomi,^{23b,23a} P. Giannetti,^{70a}
 A. Giannini,^{68a,68b} S. M. Gibson,⁹² M. Gignac,¹⁴⁵ D. Gillberg,³⁴ G. Gilles,¹⁸¹ D. M. Gingrich,^{3,d} M. P. Giordani,^{65a,65c}
 F. M. Giorgi,^{23b} P. F. Giraud,¹⁴⁴ P. Giromini,⁵⁸ G. Giugliarelli,^{65a,65c} D. Giugni,^{67a} F. Giuli,¹³⁴ M. Giulini,^{60b} S. Gkaitatzis,¹⁶¹
 I. Gkialas,^{9,s} E. L. Gkoukousis,¹⁴ P. Gkoutoumis,¹⁰ L. K. Gladilin,¹¹² C. Glasman,⁹⁷ J. Glatzer,¹⁴ P. C. F. Glaysheer,⁴⁵
 A. Glazov,⁴⁵ M. Goblirsch-Kolb,²⁶ J. Godlewski,⁸³ S. Goldfarb,¹⁰³ T. Golling,⁵³ D. Golubkov,¹²² A. Gomes,^{139a,139b}
 R. Goncalves Gama,^{79a} R. Gonçalves,^{139a} G. Gonella,⁵¹ L. Gonella,²¹ A. Gongadze,⁷⁸ F. Gonnella,²¹ J. L. Gonski,⁵⁸
 S. González de la Hoz,¹⁷³ S. Gonzalez-Sevilla,⁵³ L. Goossens,³⁶ P. A. Gorbounov,¹¹⁰ H. A. Gordon,²⁹ B. Gorini,³⁶
 E. Gorini,^{66a,66b} A. Gorišek,⁹⁰ A. T. Goshaw,⁴⁸ C. Gössling,⁴⁶ M. I. Gostkin,⁷⁸ C. A. Gottardo,²⁴ C. R. Goudet,¹³¹
 D. Goujdami,^{35c} A. G. Goussiou,¹⁴⁷ N. Govender,^{33b,i} C. Goy,⁵ E. Gozani,¹⁵⁹ I. Grabowska-Bold,^{82a} P. O. J. Gradin,¹⁷¹
 E. C. Graham,⁸⁹ J. Gramling,¹⁷⁰ E. Gramstad,¹³³ S. Grancagnolo,¹⁹ V. Gratchev,¹³⁷ P. M. Gravila,^{27f} F. G. Gravili,^{66a,66b}
 C. Gray,⁵⁶ H. M. Gray,¹⁸ Z. D. Greenwood,⁹⁴ C. Greife,²⁴ K. Gregersen,⁹⁵ I. M. Gregor,⁴⁵ P. Grenier,¹⁵² K. Grevtsov,⁴⁵
 N. A. Grieser,¹²⁷ J. Griffiths,⁸ A. A. Grillo,¹⁴⁵ K. Grimm,^{31,u} S. Grinstein,^{14,v} Ph. Gris,³⁸ J.-F. Grivaz,¹³¹ S. Groh,⁹⁸
 E. Gross,¹⁷⁹ J. Grosse-Knetter,⁵² G. C. Grossi,⁹⁴ Z. J. Grout,⁹³ C. Grud,¹⁰⁴ A. Grummer,¹¹⁷ L. Guan,¹⁰⁴ W. Guan,¹⁸⁰
 J. Guenther,³⁶ A. Guerguichon,¹³¹ F. Guescini,^{167a} D. Guest,¹⁷⁰ R. Gugel,⁵¹ B. Gui,¹²⁵ T. Guillemin,⁵ S. Guindon,³⁶ U. Gul,⁵⁶
 C. Gumpert,³⁶ J. Guo,^{59c} W. Guo,¹⁰⁴ Y. Guo,^{59a,w} Z. Guo,¹⁰⁰ R. Gupta,⁴⁵ S. Gurbuz,^{12c} G. Gustavino,¹²⁷ B. J. Gutelman,¹⁵⁹
 P. Gutierrez,¹²⁷ C. Gutschow,⁹³ C. Guyot,¹⁴⁴ M. P. Guzik,^{82a} C. Gwenlan,¹³⁴ C. B. Gwilliam,⁸⁹ A. Haas,¹²³ C. Haber,¹⁸
 H. K. Hadavand,⁸ N. Haddad,^{35e} A. Hadeif,^{59a} S. Hageböck,²⁴ M. Hagihara,¹⁶⁸ H. Hakobyan,^{183,a} M. Haleem,¹⁷⁶ J. Haley,¹²⁸
 G. Halladjian,¹⁰⁵ G. D. Hallewell,¹⁰⁰ K. Hamacher,¹⁸¹ P. Hamal,¹²⁹ K. Hamano,¹⁷⁵ A. Hamilton,^{33a} G. N. Hamity,¹⁴⁸
 K. Han,^{59a,x} L. Han,^{59a} S. Han,^{15a,15d} K. Hanagaki,^{80,y} M. Hance,¹⁴⁵ D. M. Handl,¹¹³ B. Haney,¹³⁶ R. Hankache,¹³⁵
 P. Hanke,^{60a} E. Hansen,⁹⁵ J. B. Hansen,⁴⁰ J. D. Hansen,⁴⁰ M. C. Hansen,²⁴ P. H. Hansen,⁴⁰ E. C. Hanson,⁹⁹ K. Hara,¹⁶⁸
 A. S. Hard,¹⁸⁰ T. Harenberg,¹⁸¹ S. Harkusha,¹⁰⁶ P. F. Harrison,¹⁷⁷ N. M. Hartmann,¹¹³ Y. Hasegawa,¹⁴⁹ A. Hasib,⁴⁹
 S. Hassani,¹⁴⁴ S. Haug,²⁰ R. Hauser,¹⁰⁵ L. Hauswald,⁴⁷ L. B. Havener,³⁹ M. Havranek,¹⁴¹ C. M. Hawkes,²¹ R. J. Hawkings,³⁶
 D. Hayden,¹⁰⁵ C. Hayes,¹⁵⁴ C. P. Hays,¹³⁴ J. M. Hays,⁹¹ H. S. Hayward,⁸⁹ S. J. Haywood,¹⁴³ M. P. Heath,⁴⁹ V. Hedberg,⁹⁵
 L. Heelan,⁸ S. Heer,²⁴ K. K. Heidegger,⁵¹ J. Heilman,³⁴ S. Heim,⁴⁵ T. Heim,¹⁸ B. Heinemann,^{45,z} J. J. Heinrich,¹¹³
 L. Heinrich,¹²³ C. Heinz,⁵⁵ J. Hejbal,¹⁴⁰ L. Helary,³⁶ A. Held,¹⁷⁴ S. Hellesund,¹³³ S. Hellman,^{44a,44b} C. Helsens,³⁶
 R. C. W. Henderson,⁸⁸ Y. Heng,¹⁸⁰ S. Henkelmann,¹⁷⁴ A. M. Henriques Correia,³⁶ G. H. Herbert,¹⁹ H. Herde,²⁶ V. Herget,¹⁷⁶
 Y. Hernández Jiménez,^{33c} H. Herr,⁹⁸ M. G. Herrmann,¹¹³ T. Herrmann,⁴⁷ G. Herten,⁵¹ R. Hertenberger,¹¹³ L. Hervas,³⁶
 T. C. Herwig,¹³⁶ G. G. Hesketh,⁹³ N. P. Hessey,^{167a} A. Higashida,¹⁶² S. Higashino,⁸⁰ E. Higón-Rodríguez,¹⁷³
 K. Hildebrand,³⁷ E. Hill,¹⁷⁵ J. C. Hill,³² K. K. Hill,²⁹ K. H. Hiller,⁴⁵ S. J. Hillier,²¹ M. Hils,⁴⁷ I. Hinchliffe,¹⁸ M. Hirose,¹³²
 D. Hirschbuehl,¹⁸¹ B. Hiti,⁹⁰ O. Hladik,¹⁴⁰ D. R. Hlaluku,^{33c} X. Hoad,⁴⁹ J. Hobbs,¹⁵⁴ N. Hod,^{167a} M. C. Hodgkinson,¹⁴⁸
 A. Hoecker,³⁶ M. R. Hoefkamp,¹¹⁷ F. Hoenig,¹¹³ D. Hohn,²⁴ D. Hohov,¹³¹ T. R. Holmes,³⁷ M. Holzbock,¹¹³ M. Homann,⁴⁶
 S. Honda,¹⁶⁸ T. Honda,⁸⁰ T. M. Hong,¹³⁸ A. Hönle,¹¹⁴ B. H. Hooberman,¹⁷² W. H. Hopkins,¹³⁰ Y. Horii,¹¹⁶ P. Horn,⁴⁷
 A. J. Horton,¹⁵¹ L. A. Horyn,³⁷ J.-Y. Hostachy,⁵⁷ A. Hostiuc,¹⁴⁷ S. Hou,¹⁵⁷ A. Hoummada,^{35a} J. Howarth,⁹⁹ J. Hoya,⁸⁷
 M. Hrabovsky,¹²⁹ J. Hrdinka,³⁶ I. Hristova,¹⁹ J. Hrivnac,¹³¹ A. Hrynevich,¹⁰⁷ T. Hryn'ova,⁵ P. J. Hsu,⁶³ S.-C. Hsu,¹⁴⁷ Q. Hu,²⁹
 S. Hu,^{59c} Y. Huang,^{15a} Z. Hubacek,¹⁴¹ F. Hubaut,¹⁰⁰ M. Huebner,²⁴ F. Huegging,²⁴ T. B. Huffman,¹³⁴ M. Huhtinen,³⁶
 R. F. H. Hunter,³⁴ P. Huo,¹⁵⁴ A. M. Hupe,³⁴ N. Huseynov,^{78,c} J. Huston,¹⁰⁵ J. Huth,⁵⁸ R. Hyneman,¹⁰⁴ G. Iacobucci,⁵³

- G. Iakovidis,²⁹ I. Ibragimov,¹⁵⁰ L. Iconomidou-Fayard,¹³¹ Z. Idrissi,^{35e} P. I. Iengo,³⁶ R. Ignazzi,⁴⁰ O. Igonkina,^{119,a,aa}
 R. Iguchi,¹⁶² T. Iizawa,⁵³ Y. Ikegami,⁸⁰ M. Ikeno,⁸⁰ D. Iliadis,¹⁶¹ N. Ilic,¹¹⁸ F. Iltzsche,⁴⁷ G. Introzzi,^{69a,69b} M. Iodice,^{73a}
 K. Iordanidou,³⁹ V. Ippolito,^{71a,71b} M. F. Isacson,¹⁷¹ N. Ishijima,¹³² M. Ishino,¹⁶² M. Ishitsuka,¹⁶⁴ W. Islam,¹²⁸ C. Issever,¹³⁴
 S. Istin,¹⁵⁹ F. Ito,¹⁶⁸ J. M. Iturbe Ponce,^{62a} R. Iuppa,^{74a,74b} A. Ivina,¹⁷⁹ H. Iwasaki,⁸⁰ J. M. Izen,⁴³ V. Izzo,^{68a} P. Jacka,¹⁴⁰
 P. Jackson,¹ R. M. Jacobs,²⁴ V. Jain,² G. Jäkel,¹⁸¹ K. B. Jakobi,⁹⁸ K. Jakobs,⁵¹ S. Jakobsen,⁷⁵ T. Jakoubek,¹⁴⁰ D. O. Jamin,¹²⁸
 R. Jansky,⁵³ J. Janssen,²⁴ M. Janus,⁵² P. A. Janus,^{82a} G. Jarlskog,⁹⁵ N. Javadov,^{78,c} T. Javůrek,³⁶ M. Javurkova,⁵¹
 F. Jeanneau,¹⁴⁴ L. Jeanty,¹⁸ J. Jejelava,^{158a,bb} A. Jelinskas,¹⁷⁷ P. Jenni,^{51,cc} J. Jeong,⁴⁵ N. Jeong,⁴⁵ S. Jézéquel,⁵ H. Ji,¹⁸⁰
 J. Jia,¹⁵⁴ H. Jiang,⁷⁷ Y. Jiang,^{59a} Z. Jiang,¹⁵² S. Jiggins,⁵¹ F. A. Jimenez Morales,³⁸ J. Jimenez Pena,¹⁷³ S. Jin,^{15c} A. Jinaru,^{27b}
 O. Jinnouchi,¹⁶⁴ H. Jivan,^{33c} P. Johansson,¹⁴⁸ K. A. Johns,⁷ C. A. Johnson,⁶⁴ W. J. Johnson,¹⁴⁷ K. Jon-And,^{44a,44b}
 R. W. L. Jones,⁸⁸ S. D. Jones,¹⁵⁵ S. Jones,⁷ T. J. Jones,⁸⁹ J. Jongmanns,^{60a} P. M. Jorge,^{139a,139b} J. Jovicevic,^{167a} X. Ju,¹⁸
 J. J. Junggeburth,¹¹⁴ A. Juste Rozas,^{14,v} A. Kaczmarek,⁸³ M. Kado,¹³¹ H. Kagan,¹²⁵ M. Kagan,¹⁵² T. Kaji,¹⁷⁸
 E. Kajomovitz,¹⁵⁹ C. W. Kalderon,⁹⁵ A. Kaluza,⁹⁸ S. Kama,⁴² A. Kamenshchikov,¹²² L. Kanjir,⁹⁰ Y. Kano,¹⁶²
 V. A. Kantserov,¹¹¹ J. Kanzaki,⁸⁰ B. Kaplan,¹²³ L. S. Kaplan,¹⁸⁰ D. Kar,^{33c} M. J. Kareem,^{167b} E. Karentzos,¹⁰ S. N. Karpov,⁷⁸
 Z. M. Karpova,⁷⁸ V. Kartvelishvili,⁸⁸ A. N. Karyukhin,¹²² L. Kashif,¹⁸⁰ R. D. Kass,¹²⁵ A. Kastanas,^{44a,44b} Y. Kataoka,¹⁶²
 C. Kato,^{59d,59c} J. Katzy,⁴⁵ K. Kawade,⁸¹ K. Kawagoe,⁸⁶ T. Kawamoto,¹⁶² G. Kawamura,⁵² E. F. Kay,⁸⁹ V. F. Kazanin,^{121b,121a}
 R. Keeler,¹⁷⁵ R. Kehoe,⁴² J. S. Keller,³⁴ E. Kellermann,⁹⁵ J. J. Kempster,²¹ J. Kendrick,²¹ O. Kepka,¹⁴⁰ S. Kersten,¹⁸¹
 B. P. Kerševan,⁹⁰ S. Ketabchi Haghighat,¹⁶⁶ R. A. Keyes,¹⁰² M. Khader,¹⁷² F. Khalil-Zada,¹³ A. Khanov,¹²⁸
 A. G. Kharlamov,^{121b,121a} T. Kharlamova,^{121b,121a} E. E. Khoda,¹⁷⁴ A. Khodinov,¹⁶⁵ T. J. Khoo,⁵³ E. Khramov,⁷⁸
 J. Khubua,^{158b} S. Kido,⁸¹ M. Kiehn,⁵³ C. R. Kilby,⁹² Y. K. Kim,³⁷ N. Kimura,^{65a,65c} O. M. Kind,¹⁹ B. T. King,^{89,a}
 D. Kirchmeier,⁴⁷ J. Kirk,¹⁴³ A. E. Kiryunin,¹¹⁴ T. Kishimoto,¹⁶² D. Kisielewska,^{82a} V. Kitali,⁴⁵ O. Kivernyk,⁵ E. Kladiya,^{28b,a}
 T. Klapdor-Kleingrothaus,⁵¹ M. H. Klein,¹⁰⁴ M. Klein,⁸⁹ U. Klein,⁸⁹ K. Kleinknecht,⁹⁸ P. Klimek,¹²⁰ A. Klimentov,²⁹
 T. Klingl,²⁴ T. Klioutchnikova,³⁶ F. F. Klitzner,¹¹³ P. Kluit,¹¹⁹ S. Kluth,¹¹⁴ E. Kneringer,⁷⁵ E. B. F. G. Knoop,¹⁰⁰ A. Knue,⁵¹
 A. Kobayashi,¹⁶² D. Kobayashi,⁸⁶ T. Kobayashi,¹⁶² M. Kobel,⁴⁷ M. Kocian,¹⁵² P. Kodys,¹⁴² P. T. Koenig,²⁴ T. Koffas,³⁴
 E. Koffeman,¹¹⁹ N. M. Köhler,¹¹⁴ T. Koi,¹⁵² M. Kolb,^{60b} I. Koletsou,⁵ T. Kondo,⁸⁰ N. Kondrashova,^{59c} K. Köneke,⁵¹
 A. C. König,¹¹⁸ T. Kono,¹²⁴ R. Konoplich,^{123,dd} V. Konstantinides,⁹³ N. Konstantinidis,⁹³ B. Konya,⁹⁵ R. Kopeliashvili,⁶⁴
 S. Koperny,^{82a} K. Korcyl,⁸³ K. Kordas,¹⁶¹ G. Koren,¹⁶⁰ A. Korn,⁹³ I. Korolkov,¹⁴ E. V. Korolkova,¹⁴⁸ N. Korotkova,¹¹²
 O. Kortner,¹¹⁴ S. Kortner,¹¹⁴ T. Kosek,¹⁴² V. V. Kostyukhin,²⁴ A. Kotwal,⁴⁸ A. Koulouris,¹⁰
 A. Kourkoulis-Charalampidi,^{69a,69b} C. Kourkoulis,⁹ E. Kourlitis,¹⁴⁸ V. Kouskoura,²⁹ A. B. Kowalewska,⁸³
 R. Kowalewski,¹⁷⁵ T. Z. Kowalski,^{82a} C. Kozakai,¹⁶² W. Kozanecki,¹⁴⁴ A. S. Kozhin,¹²² V. A. Kramarenko,¹¹²
 G. Kramberger,⁹⁰ D. Krasnopevtsev,^{59a} M. W. Krasny,¹³⁵ A. Krasznahorkay,³⁶ D. Krauss,¹¹⁴ J. A. Kremer,^{82a}
 J. Kretschmar,⁸⁹ P. Krieger,¹⁶⁶ K. Krizka,¹⁸ K. Kroeninger,⁴⁶ H. Kroha,¹¹⁴ J. Kroll,¹⁴⁰ J. Kroll,¹³⁶ J. Krstic,¹⁶
 U. Kruchonak,⁷⁸ H. Krüger,²⁴ N. Krumnack,⁷⁷ M. C. Kruse,⁴⁸ T. Kubota,¹⁰³ S. Kuday,^{4b} J. T. Kuechler,¹⁸¹ S. Kuehn,³⁶
 A. Kugel,^{60a} F. Kuger,¹⁷⁶ T. Kuhl,⁴⁵ V. Kukhtin,⁷⁸ R. Kukla,¹⁰⁰ Y. Kulchitsky,¹⁰⁶ S. Kuleshov,^{146b} Y. P. Kulinich,¹⁷²
 M. Kuna,⁵⁷ T. Kunigo,⁸⁴ A. Kupco,¹⁴⁰ T. Kupfer,⁴⁶ O. Kuprash,¹⁶⁰ H. Kurashige,⁸¹ L. L. Kurchaninov,^{167a}
 Y. A. Kurochkin,¹⁰⁶ A. Kurova,¹¹¹ M. G. Kurth,^{15a,15d} E. S. Kuwertz,³⁶ M. Kuze,¹⁶⁴ J. Kvita,¹²⁹ T. Kwan,¹⁰² A. La Rosa,¹¹⁴
 J. L. La Rosa Navarro,^{79d} L. La Rotonda,^{41b,41a} F. La Ruffa,^{41b,41a} C. Lacasta,¹⁷³ F. Lacava,^{71a,71b} J. Lacey,⁴⁵ D. P. J. Lack,⁹⁹
 H. Lacker,¹⁹ D. Lacour,¹³⁵ E. Ladygin,⁷⁸ R. Lafaye,⁵ B. Laforge,¹³⁵ T. Lagouri,^{33c} S. Lai,⁵² S. Lammers,⁶⁴ W. Lampl,⁷
 E. Lançon,²⁹ U. Landgraf,⁵¹ M. P. J. Landon,⁹¹ M. C. Lanfermann,⁵³ V. S. Lang,⁴⁵ J. C. Lange,⁵² R. J. Langenberg,³⁶
 A. J. Lankford,¹⁷⁰ F. Lanni,²⁹ K. Lantzsch,²⁴ A. Lanza,^{69a} A. Lapertosa,^{54b,54a} S. Laplace,¹³⁵ J. F. Laporte,¹⁴⁴ T. Lari,^{67a}
 F. Lasagni Manghi,^{23b,23a} M. Lassnig,³⁶ T. S. Lau,^{62a} A. Laudrain,¹³¹ M. Lavorgna,^{68a,68b} M. Lazzaroni,^{67a,67b} B. Le,¹⁰³
 O. Le Dortz,¹³⁵ E. Le Guirriec,¹⁰⁰ E. P. Le Quilleuc,¹⁴⁴ M. LeBlanc,⁷ T. LeCompte,⁶ F. Ledroit-Guillon,⁵⁷ C. A. Lee,²⁹
 G. R. Lee,^{146a} L. Lee,⁵⁸ S. C. Lee,¹⁵⁷ B. Lefebvre,¹⁰² M. Lefebvre,¹⁷⁵ F. Legger,¹¹³ C. Leggett,¹⁸ K. Lehmann,¹⁵¹
 N. Lehmann,¹⁸¹ G. Lehmann Miotto,³⁶ W. A. Leight,⁴⁵ A. Leisos,^{161,ee} M. A. L. Leite,^{79d} R. Leitner,¹⁴² D. Lellouch,^{179,a}
 K. J. C. Leney,⁹³ T. Lenz,²⁴ B. Lenzi,³⁶ R. Leone,⁷ S. Leone,^{70a} C. Leonidopoulos,⁴⁹ G. Lerner,¹⁵⁵ C. Leroy,¹⁰⁸ R. Les,¹⁶⁶
 A. A. J. Lesage,¹⁴⁴ C. G. Lester,³² M. Levchenko,¹³⁷ J. Levêque,⁵ D. Levin,¹⁰⁴ L. J. Levinson,¹⁷⁹ D. Lewis,⁹¹ B. Li,^{15b}
 B. Li,¹⁰⁴ C-Q. Li,^{59a,ff} H. Li,^{59b} L. Li,^{59c} M. Li,^{15a} Q. Li,^{15a,15d} Q. Y. Li,^{59a} S. Li,^{59d,59c} X. Li,^{59c} Y. Li,¹⁵⁰ Z. Liang,^{15a}
 B. Liberti,^{72a} A. Liblong,¹⁶⁶ K. Lie,^{62c} S. Liem,¹¹⁹ A. Limosani,¹⁵⁶ C. Y. Lin,³² K. Lin,¹⁰⁵ T. H. Lin,⁹⁸ R. A. Linck,⁶⁴
 J. H. Lindon,²¹ B. E. Lindquist,¹⁵⁴ A. L. Lioni,⁵³ E. Lipeles,¹³⁶ A. Lipniacka,¹⁷ M. Lisovsky,^{60b} T. M. Liss,^{172,gg} A. Lister,¹⁷⁴
 A. M. Litke,¹⁴⁵ J. D. Little,⁸ B. Liu,⁷⁷ B. L. Liu,⁶ H. B. Liu,²⁹ H. Liu,¹⁰⁴ J. B. Liu,^{59a} J. K. K. Liu,¹³⁴ K. Liu,¹³⁵ M. Liu,^{59a}

P. Liu,¹⁸ Y. Liu,^{15a,15d} Y. L. Liu,^{59a} Y. W. Liu,^{59a} M. Livan,^{69a,69b} A. Lleres,⁵⁷ J. Llorente Merino,^{15a} S. L. Lloyd,⁹¹ C. Y. Lo,^{62b}
 F. Lo Sterzo,⁴² E. M. Lobodzinska,⁴⁵ P. Loch,⁷ T. Lohse,¹⁹ K. Lohwasser,¹⁴⁸ M. Lokajicek,¹⁴⁰ J. D. Long,¹⁷² R. E. Long,⁸⁸
 L. Longo,^{66a,66b} K. A. Looper,¹²⁵ J. A. Lopez,^{146b} I. Lopez Paz,⁹⁹ A. Lopez Solis,¹⁴⁸ J. Lorenz,¹¹³ N. Lorenzo Martinez,⁵
 M. Losada,²² P. J. Lösel,¹¹³ A. Lösle,⁵¹ X. Lou,⁴⁵ X. Lou,^{15a} A. Lounis,¹³¹ J. Love,⁶ P. A. Love,⁸⁸ J. J. Lozano Bahilo,¹⁷³
 H. Lu,^{62a} M. Lu,^{59a} N. Lu,¹⁰⁴ Y. J. Lu,⁶³ H. J. Lubatti,¹⁴⁷ C. Luci,^{71a,71b} A. Lucotte,⁵⁷ C. Luedtke,⁵¹ F. Luehring,⁶⁴ I. Luise,¹³⁵
 L. Luminari,^{71a} B. Lund-Jensen,¹⁵³ M. S. Lutz,¹⁰¹ P. M. Luzzi,¹³⁵ D. Lynn,²⁹ R. Lysak,¹⁴⁰ E. Lytken,⁹⁵ F. Lyu,^{15a}
 V. Lyubushkin,⁷⁸ T. Lyubushkina,⁷⁸ H. Ma,²⁹ L. L. Ma,^{59b} Y. Ma,^{59b} G. Maccarrone,⁵⁰ A. Macchiolo,¹¹⁴
 C. M. Macdonald,¹⁴⁸ J. Machado Miguens,^{136,139b} D. Madaffari,¹⁷³ R. Madar,³⁸ W. F. Mader,⁴⁷ A. Madsen,⁴⁵ N. Madysa,⁴⁷
 J. Maeda,⁸¹ K. Maekawa,¹⁶² S. Maeland,¹⁷ T. Maeno,²⁹ M. Maerker,⁴⁷ A. S. Maevskiy,¹¹² V. Magerl,⁵¹ D. J. Mahon,³⁹
 C. Maidantchik,^{79b} T. Maier,¹¹³ A. Maio,^{139a,139b,139d} O. Majersky,^{28a} S. Majewski,¹³⁰ Y. Makida,⁸⁰ N. Makovec,¹³¹
 B. Malaescu,¹³⁵ Pa. Malecki,⁸³ V. P. Maleev,¹³⁷ F. Malek,⁵⁷ U. Mallik,⁷⁶ D. Malon,⁶ C. Malone,³² S. Maltezos,¹⁰
 S. Malyukov,³⁶ J. Mamuzic,¹⁷³ G. Mancini,⁵⁰ I. Mandić,⁹⁰ J. Maneira,^{139a} L. Manhaes de Andrade Filho,^{79a}
 J. Manjarres Ramos,⁴⁷ K. H. Mankinen,⁹⁵ A. Mann,¹¹³ A. Manousos,⁷⁵ B. Mansoulie,¹⁴⁴ J. D. Mansour,^{15a} M. Mantoani,⁵²
 S. Manzoni,^{67a,67b} A. Marantis,¹⁶¹ G. Marceca,³⁰ L. March,⁵³ L. Marchese,¹³⁴ G. Marchiori,¹³⁵ M. Marcisovsky,¹⁴⁰
 C. A. Marin Tobon,³⁶ M. Marjanovic,³⁸ D. E. Marley,¹⁰⁴ F. Marroquin,^{79b} Z. Marshall,¹⁸ M. U. F. Martensson,¹⁷¹
 S. Marti-Garcia,¹⁷³ C. B. Martin,¹²⁵ T. A. Martin,¹⁷⁷ V. J. Martin,⁴⁹ B. Martin dit Latour,¹⁷ M. Martinez,^{14,v}
 V. I. Martinez Outschoorn,¹⁰¹ S. Martin-Haugh,¹⁴³ V. S. Martoiu,^{27b} A. C. Martyniuk,⁹³ A. Marzin,³⁶ L. Masetti,⁹⁸
 T. Mashimo,¹⁶² R. Mashinistov,¹⁰⁹ J. Masik,⁹⁹ A. L. Maslennikov,^{121b,121a} L. H. Mason,¹⁰³ L. Massa,^{72a,72b}
 P. Massarotti,^{68a,68b} P. Mastrandrea,⁵ A. Mastroberardino,^{41b,41a} T. Masubuchi,¹⁶² P. Mättig,¹⁸¹ J. Maurer,^{27b} B. Maček,⁹⁰
 S. J. Maxfield,⁸⁹ D. A. Maximov,^{121b,121a} R. Mazini,¹⁵⁷ I. Maznas,¹⁶¹ S. M. Mazza,¹⁴⁵ G. Mc Goldrick,¹⁶⁶ S. P. Mc Kee,¹⁰⁴
 T. G. McCarthy,¹¹⁴ L. I. McClymont,⁹³ E. F. McDonald,¹⁰³ J. A. Mcfayden,³⁶ M. A. McKay,⁴² K. D. McLean,¹⁷⁵
 S. J. McMahon,¹⁴³ P. C. McNamara,¹⁰³ C. J. McNicol,¹⁷⁷ R. A. McPherson,^{175,m} J. E. Mdhluli,^{33c} Z. A. Meadows,¹⁰¹
 S. Meehan,¹⁴⁷ T. Megy,⁵¹ S. Mehlhase,¹¹³ A. Mehta,⁸⁹ T. Meideck,⁵⁷ B. Meirose,⁴³ D. Melini,^{173,hh} B. R. Mellado Garcia,^{33c}
 J. D. Mellenthin,⁵² M. Melo,^{28a} F. Meloni,⁴⁵ A. Melzer,²⁴ S. B. Menary,⁹⁹ E. D. Mendes Gouveia,^{139a} L. Meng,⁸⁹
 X. T. Meng,¹⁰⁴ A. Mengarelli,^{23b,23a} S. Menke,¹¹⁴ E. Meoni,^{41b,41a} S. Mergelmeyer,¹⁹ S. A. M. Merkt,¹³⁸ C. Merlassino,²⁰
 P. Mermod,⁵³ L. Merola,^{68a,68b} C. Meroni,^{67a} F. S. Merritt,³⁷ A. Messina,^{71a,71b} J. Metcalfe,⁶ A. S. Mete,¹⁷⁰ C. Meyer,¹³⁶
 J. Meyer,¹⁵⁹ J-P. Meyer,¹⁴⁴ H. Meyer Zu Theenhausen,^{60a} F. Miano,¹⁵⁵ R. P. Middleton,¹⁴³ L. Mijović,⁴⁹ G. Mikenberg,¹⁷⁹
 M. Mikestikova,¹⁴⁰ M. Mikuž,⁹⁰ M. Milesi,¹⁰³ A. Milic,¹⁶⁶ D. A. Millar,⁹¹ D. W. Miller,³⁷ A. Milov,¹⁷⁹ D. A. Milstead,^{44a,44b}
 A. A. Minaenko,¹²² M. Miñano Moya,¹⁷³ I. A. Minashvili,^{158b} A. I. Mincer,¹²³ B. Mindur,^{82a} M. Mineev,⁷⁸ Y. Minegishi,¹⁶²
 Y. Ming,¹⁸⁰ L. M. Mir,¹⁴ A. Mirto,^{66a,66b} K. P. Mistry,¹³⁶ T. Mitani,¹⁷⁸ J. Mitrevski,¹¹³ V. A. Mitsou,¹⁷³ M. Mittal,^{59c}
 A. Miucci,²⁰ P. S. Miyagawa,¹⁴⁸ A. Mizukami,⁸⁰ J. U. Mjörnmark,⁹⁵ T. Mkrtchyan,¹⁸³ M. Mlynarikova,¹⁴² T. Moa,^{44a,44b}
 K. Mochizuki,¹⁰⁸ P. Mogg,⁵¹ S. Mohapatra,³⁹ S. Molander,^{44a,44b} R. Moles-Valls,²⁴ M. C. Mondragon,¹⁰⁵ K. Mönig,⁴⁵
 J. Monk,⁴⁰ E. Monnier,¹⁰⁰ A. Montalbano,¹⁵¹ J. Montejo Berlingen,³⁶ F. Monticelli,⁸⁷ S. Monzani,^{67a} N. Morange,¹³¹
 D. Moreno,²² M. Moreno Llácer,³⁶ P. Morettini,^{54b} M. Morgenstern,¹¹⁹ S. Morgenstern,⁴⁷ D. Mori,¹⁵¹ M. Morii,⁵⁸
 M. Morinaga,¹⁷⁸ V. Morisbak,¹³³ A. K. Morley,³⁶ G. Mornacchi,³⁶ A. P. Morris,⁹³ J. D. Morris,⁹¹ L. Morvaj,¹⁵⁴
 P. Moschovakos,¹⁰ M. Mosidze,^{158b} H. J. Moss,¹⁴⁸ J. Moss,^{31,ji} K. Motohashi,¹⁶⁴ R. Mount,¹⁵² E. Mountricha,³⁶
 E. J. W. Moyse,¹⁰¹ S. Muanza,¹⁰⁰ F. Mueller,¹¹⁴ J. Mueller,¹³⁸ R. S. P. Mueller,¹¹³ D. Muenstermann,⁸⁸ G. A. Mullier,⁹⁵
 F. J. Munoz Sanchez,⁹⁹ P. Murin,^{28b} W. J. Murray,^{177,143} A. Murrone,^{67a,67b} M. Muškinja,⁹⁰ C. Mwewa,^{33a}
 A. G. Myagkov,^{122,ji} J. Myers,¹³⁰ M. Myska,¹⁴¹ B. P. Nachman,¹⁸ O. Nackenhorst,⁴⁶ K. Nagai,¹³⁴ K. Nagano,⁸⁰
 Y. Nagasaka,⁶¹ M. Nagel,⁵¹ E. Nagy,¹⁰⁰ A. M. Nairz,³⁶ Y. Nakahama,¹¹⁶ K. Nakamura,¹⁶² T. Nakamura,¹⁶² I. Nakano,¹²⁶
 H. Nanjo,¹³² F. Napolitano,^{60a} R. F. Naranjo Garcia,⁴⁵ R. Narayan,¹¹ D. I. Narrias Villar,^{60a} I. Naryshkin,¹³⁷ T. Naumann,⁴⁵
 G. Navarro,²² R. Nayyar,⁷ H. A. Neal,^{104,a} P. Y. Nechaeva,¹⁰⁹ T. J. Neep,¹⁴⁴ A. Negri,^{69a,69b} M. Negrini,^{23b} S. Nektarijevic,¹¹⁸
 C. Nellist,⁵² M. E. Nelson,¹³⁴ S. Nemecek,¹⁴⁰ P. Nemethy,¹²³ M. Nessi,^{36,kk} M. S. Neubauer,¹⁷² M. Neumann,¹⁸¹
 P. R. Newman,²¹ T. Y. Ng,^{62c} Y. S. Ng,¹⁹ H. D. N. Nguyen,¹⁰⁰ T. Nguyen Manh,¹⁰⁸ E. Nibigira,³⁸ R. B. Nickerson,¹³⁴
 R. Nicolaidou,¹⁴⁴ D. S. Nielsen,⁴⁰ J. Nielsen,¹⁴⁵ N. Nikiforou,¹¹ V. Nikolaenko,^{122,ji} I. Nikolic-Audit,¹³⁵ K. Nikolopoulos,²¹
 P. Nilsson,²⁹ Y. Ninomiya,⁸⁰ A. Nisati,^{71a} N. Nishu,^{59c} R. Nisius,¹¹⁴ I. Nitsche,⁴⁶ T. Nitta,¹⁷⁸ T. Nobe,¹⁶² Y. Noguchi,⁸⁴
 M. Nomachi,¹³² I. Nomidis,¹³⁵ M. A. Nomura,²⁹ T. Nooney,⁹¹ M. Nordberg,³⁶ N. Norjoharuddeen,¹³⁴ T. Novak,⁹⁰
 O. Novgorodova,⁴⁷ R. Novotny,¹⁴¹ L. Nozka,¹²⁹ K. Ntekas,¹⁷⁰ E. Nurse,⁹³ F. Nuti,¹⁰³ F. G. Oakham,^{34,d} H. Oberlack,¹¹⁴
 J. Ocariz,¹³⁵ A. Ochi,⁸¹ I. Ochoa,³⁹ J. P. Ochoa-Ricoux,^{146a} K. O'Connor,²⁶ S. Oda,⁸⁶ S. Odaka,⁸⁰ S. Oerdek,⁵² A. Oh,⁹⁹

- S. H. Oh,⁴⁸ C. C. Ohm,¹⁵³ H. Oide,^{54b,54a} M. L. Ojeda,¹⁶⁶ H. Okawa,¹⁶⁸ Y. Okazaki,⁸⁴ Y. Okumura,¹⁶² T. Okuyama,⁸⁰
 A. Olariu,^{27b} L. F. Oleiro Seabra,^{139a} S. A. Olivares Pino,^{146a} D. Oliveira Damazio,²⁹ J. L. Oliver,¹ M. J. R. Olsson,³⁷
 A. Olszewski,⁸³ J. Olszowska,⁸³ D. C. O'Neil,¹⁵¹ A. Onofre,^{139a,139e} K. Onogi,¹¹⁶ P. U. E. Onyisi,¹¹ H. Oppen,¹³³
 M. J. Oreglia,³⁷ G. E. Orellana,⁸⁷ Y. Oren,¹⁶⁰ D. Orestano,^{73a,73b} N. Orlando,^{62b} A. A. O'Rourke,⁴⁵ R. S. Orr,¹⁶⁶
 B. Osculati,^{54b,54a,a} V. O'Shea,⁵⁶ R. Ospanov,^{59a} G. Otero y Garzon,³⁰ H. Otono,⁸⁶ M. Ouchrif,^{35d} F. Ould-Saada,¹³³
 A. Ouraou,¹⁴⁴ Q. Ouyang,^{15a} M. Owen,⁵⁶ R. E. Owen,²¹ V. E. Ozcan,^{12c} N. Ozturk,⁸ J. Pacalt,¹²⁹ H. A. Pacey,³² K. Pachal,¹⁵¹
 A. Pacheco Pages,¹⁴ L. Pacheco Rodriguez,¹⁴⁴ C. Padilla Aranda,¹⁴ S. Pagan Griso,¹⁸ M. Paganini,¹⁸² G. Palacino,⁶⁴
 S. Palazzo,⁴⁹ S. Palestini,³⁶ M. Palka,^{82b} D. Pallin,³⁸ I. Panagoulas,¹⁰ C. E. Pandini,³⁶ J. G. Panduro Vazquez,⁹² P. Pani,³⁶
 G. Panizzo,^{65a,65c} L. Paolozzi,⁵³ T. D. Papadopoulou,¹⁰ K. Papageorgiou,^{9,s} A. Paramonov,⁶ D. Paredes Hernandez,^{62b}
 S. R. Paredes Saenz,¹³⁴ B. Parida,¹⁶⁵ T. H. Park,³⁴ A. J. Parker,⁸⁸ K. A. Parker,⁴⁵ M. A. Parker,³² F. Parodi,^{54b,54a}
 J. A. Parsons,³⁹ U. Parzefall,⁵¹ V. R. Pascuzzi,¹⁶⁶ J. M. P. Pasner,¹⁴⁵ E. Pasqualucci,^{71a} S. Passaggio,^{54b} F. Pastore,⁹²
 P. Pasuwan,^{44a,44b} S. Pataraja,⁹⁸ J. R. Pater,⁹⁹ A. Pathak,¹⁸⁰ T. Pauly,³⁶ B. Pearson,¹¹⁴ M. Pedersen,¹³³ L. Pedraza Diaz,¹¹⁸
 R. Pedro,^{139a,139b} S. V. Peleganchuk,^{121b,121a} O. Penc,¹⁴⁰ C. Peng,^{15a} H. Peng,^{59a} B. S. Peralva,^{79a} M. M. Perego,¹³¹
 A. P. Pereira Peixoto,^{139a} D. V. Perepelitsa,²⁹ F. Peri,¹⁹ L. Perini,^{67a,67b} H. Pernegger,³⁶ S. Perrella,^{68a,68b}
 V. D. Peshekhonov,^{78,a} K. Peters,⁴⁵ R. F. Y. Peters,⁹⁹ B. A. Petersen,³⁶ T. C. Petersen,⁴⁰ E. Petit,⁵⁷ A. Petridis,¹ C. Petridou,¹⁶¹
 P. Petroff,¹³¹ M. Petrov,¹³⁴ F. Petrucci,^{73a,73b} M. Pettee,¹⁸² N. E. Pettersson,¹⁰¹ A. Peyaud,¹⁴⁴ R. Pezoa,^{146b} T. Pham,¹⁰³
 F. H. Phillips,¹⁰⁵ P. W. Phillips,¹⁴³ M. W. Phipps,¹⁷² G. Piacquadio,¹⁵⁴ E. Pianori,¹⁸ A. Picazio,¹⁰¹ M. A. Pickering,¹³⁴
 R. H. Pickles,⁹⁹ R. Piegaia,³⁰ J. E. Pilcher,³⁷ A. D. Pilkington,⁹⁹ M. Pinamonti,^{72a,72b} J. L. Pinfold,³ M. Pitt,¹⁷⁹
 L. Pizzimento,^{72a,72b} M.-A. Pleier,²⁹ V. Pleskot,¹⁴² E. Plotnikova,⁷⁸ D. Pluth,⁷⁷ P. Podberezko,^{121b,121a} R. Poettgen,⁹⁵
 R. Poggi,⁵³ L. Poggioli,¹³¹ I. Pogrebnnyak,¹⁰⁵ D. Pohl,²⁴ I. Pokharel,⁵² G. Polesello,^{69a} A. Poley,¹⁸ A. Policicchio,^{71a,71b}
 R. Polifka,³⁶ A. Polini,^{23b} C. S. Pollard,⁴⁵ V. Polychronakos,²⁹ D. Ponomarenko,¹¹¹ L. Pontecorvo,³⁶ G. A. Popeneciu,^{27d}
 D. M. Portillo Quintero,¹³⁵ S. Pospisil,¹⁴¹ K. Potamianos,⁴⁵ I. N. Potrap,⁷⁸ C. J. Potter,³² H. Potti,¹¹ T. Poulsen,⁹⁵ J. Poveda,³⁶
 T. D. Powell,¹⁴⁸ M. E. Pozo Astigarraga,³⁶ P. Pralavorio,¹⁰⁰ S. Prell,⁷⁷ D. Price,⁹⁹ M. Primavera,^{66a} S. Prince,¹⁰²
 N. Proklova,¹¹¹ K. Prokofiev,^{62c} F. Prokoshin,^{146b} S. Protopopescu,²⁹ J. Proudfoot,⁶ M. Przybycien,^{82a} A. Puri,¹⁷² P. Puzo,¹³¹
 J. Qian,¹⁰⁴ Y. Qin,⁹⁹ A. Quadt,⁵² M. Queitsch-Maitland,⁴⁵ A. Qureshi,¹ P. Rados,¹⁰³ F. Ragusa,^{67a,67b} G. Rahal,⁹⁶
 J. A. Raine,⁵³ S. Rajagopalan,²⁹ A. Ramirez Morales,⁹¹ T. Rashid,¹³¹ S. Raspopov,⁵ M. G. Ratti,^{67a,67b} D. M. Rauch,⁴⁵
 F. Rauscher,¹¹³ S. Rave,⁹⁸ B. Ravina,¹⁴⁸ I. Ravinovich,¹⁷⁹ J. H. Rawling,⁹⁹ M. Raymond,³⁶ A. L. Read,¹³³ N. P. Readioff,⁵⁷
 M. Reale,^{66a,66b} D. M. Rebuffi,^{69a,69b} A. Redelbach,¹⁷⁶ G. Redlinger,²⁹ R. Reece,¹⁴⁵ R. G. Reed,^{33c} K. Reeves,⁴³
 L. Rehnisch,¹⁹ J. Reichert,¹³⁶ D. Reikher,¹⁶⁰ A. Reiss,⁹⁸ C. Rembser,³⁶ H. Ren,^{15a} M. Rescigno,^{71a} S. Resconi,^{67a}
 E. D. Resseguie,¹³⁶ S. Rettie,¹⁷⁴ E. Reynolds,²¹ O. L. Rezanova,^{121b,121a} P. Reznicek,¹⁴² E. Ricci,^{74a,74b} R. Richter,¹¹⁴
 S. Richter,⁴⁵ E. Richter-Was,^{82b} O. Ricken,²⁴ M. Ridel,¹³⁵ P. Rieck,¹¹⁴ C. J. Riegel,¹⁸¹ O. Rifki,⁴⁵ M. Rijssenbeek,¹⁵⁴
 A. Rimoldi,^{69a,69b} M. Rimoldi,²⁰ L. Rinaldi,^{23b} G. Ripellino,¹⁵³ B. Ristić,⁸⁸ E. Ritsch,³⁶ I. Riu,¹⁴ J. C. Rivera Vergara,^{146a}
 F. Rizatdinova,¹²⁸ E. Rizvi,⁹¹ C. Rizzi,¹⁴ R. T. Roberts,⁹⁹ S. H. Robertson,^{102,m} D. Robinson,³² J. E. M. Robinson,⁴⁵
 A. Robson,⁵⁶ E. Rocco,⁹⁸ C. Roda,^{70a,70b} Y. Rodina,¹⁰⁰ S. Rodriguez Bosca,¹⁷³ A. Rodriguez Perez,¹⁴
 D. Rodriguez Rodriguez,¹⁷³ A. M. Rodríguez Vera,^{167b} S. Roe,³⁶ C. S. Rogan,⁵⁸ O. Röhne,¹³³ R. Röhrig,¹¹⁴
 C. P. A. Roland,⁶⁴ J. Roloff,⁵⁸ A. Romaniouk,¹¹¹ M. Romano,^{23b,23a} N. Rompotis,⁸⁹ M. Ronzani,¹²³ L. Roos,¹³⁵ S. Rosati,^{71a}
 K. Rosbach,⁵¹ N.-A. Rosien,⁵² B. J. Rosser,¹³⁶ E. Rossi,⁴⁵ E. Rossi,^{73a,73b} E. Rossi,^{68a,68b} L. P. Rossi,^{54b} L. Rossini,^{67a,67b}
 J. H. N. Rosten,³² R. Rosten,¹⁴ M. Rotaru,^{27b} J. Rothberg,¹⁴⁷ D. Rousseau,¹³¹ D. Roy,^{33c} A. Rozanov,¹⁰⁰ Y. Rozen,¹⁵⁹
 X. Ruan,^{33c} F. Rubbo,¹⁵² F. Rühr,⁵¹ A. Ruiz-Martinez,¹⁷³ Z. Rurikova,⁵¹ N. A. Rusakovich,⁷⁸ H. L. Russell,¹⁰²
 J. P. Rutherford,⁷ E. M. Rüttinger,^{45,11} Y. F. Ryabov,¹³⁷ M. Rybar,¹⁷² G. Rybkin,¹³¹ S. Ryu,⁶ A. Ryzhov,¹²² G. F. Rzehorz,⁵²
 P. Sabatini,⁵² G. Sabato,¹¹⁹ S. Sacerdoti,¹³¹ H. F.-W. Sadrozinski,¹⁴⁵ R. Sadykov,⁷⁸ F. Safai Tehrani,^{71a} P. Saha,¹²⁰
 M. Sahinsoy,^{60a} A. Sahu,¹⁸¹ M. Saimpert,⁴⁵ M. Saito,¹⁶² T. Saito,¹⁶² H. Sakamoto,¹⁶² A. Sakharov,^{123,dd} D. Salamani,⁵³
 G. Salamanna,^{73a,73b} J. E. Salazar Loyola,^{146b} P. H. Sales De Bruin,¹⁷¹ D. Salihagic,^{114,a} A. Salnikov,¹⁵² J. Salt,¹⁷³
 D. Salvatore,^{41b,41a} F. Salvatore,¹⁵⁵ A. Salvucci,^{62a,62c} A. Salzburger,³⁶ J. Samarati,³⁶ D. Sammel,⁵¹ D. Sampsonidis,¹⁶¹
 D. Sampsonidou,¹⁶¹ J. Sánchez,¹⁷³ A. Sanchez Pineda,^{65a,65c} H. Sandaker,¹³³ C. O. Sander,⁴⁵ M. Sandhoff,¹⁸¹ C. Sandoval,²²
 D. P. C. Sankey,¹⁴³ M. Sannino,^{54b,54a} Y. Sano,¹¹⁶ A. Sansoni,⁵⁰ C. Santoni,³⁸ H. Santos,^{139a} I. Santoyo Castillo,¹⁵⁵
 A. Santra,¹⁷³ A. Saprnov,⁷⁸ J. G. Saraiva,^{139a,139d} O. Sasaki,⁸⁰ K. Sato,¹⁶⁸ E. Sauvan,⁵ P. Savard,^{166,d} N. Savic,¹¹⁴
 R. Sawada,¹⁶² C. Sawyer,¹⁴³ L. Sawyer,^{94,mm} C. Sbarra,^{23b} A. Sbrizzi,^{23a} T. Scanlon,⁹³ J. Schaarschmidt,¹⁴⁷ P. Schacht,¹¹⁴
 B. M. Schachtner,¹¹³ D. Schaefer,³⁷ L. Schaefer,¹³⁶ J. Schaeffer,⁹⁸ S. Schaepe,³⁶ U. Schäfer,⁹⁸ A. C. Schaffer,¹³¹

- D. Schaile,¹¹³ R. D. Schamberger,¹⁵⁴ N. Scharmberg,⁹⁹ V. A. Schegelsky,¹³⁷ D. Scheirich,¹⁴² F. Schenck,¹⁹ M. Schernau,¹⁷⁰
 C. Schiavi,^{54b,54a} S. Schier,¹⁴⁵ L. K. Schildgen,²⁴ Z. M. Schillaci,²⁶ E. J. Schioppa,³⁶ M. Schioppa,^{41b,41a} K. E. Schleicher,⁵¹
 S. Schlenker,³⁶ K. R. Schmidt-Sommerfeld,¹¹⁴ K. Schmieden,³⁶ C. Schmitt,⁹⁸ S. Schmitt,⁴⁵ S. Schmitz,⁹⁸
 J. C. Schmoeckel,⁴⁵ U. Schnoor,⁵¹ L. Schoeffel,¹⁴⁴ A. Schoening,^{60b} E. Schopf,¹³⁴ M. Schott,⁹⁸ J. F. P. Schouwenberg,¹¹⁸
 J. Schovancova,³⁶ S. Schramm,⁵³ A. Schulte,⁹⁸ H-C. Schultz-Coulon,^{60a} M. Schumacher,⁵¹ B. A. Schumm,¹⁴⁵
 Ph. Schune,¹⁴⁴ A. Schwartzman,¹⁵² T. A. Schwarz,¹⁰⁴ Ph. Schwemling,¹⁴⁴ R. Schwienhorst,¹⁰⁵ A. Sciandra,²⁴ G. Sciolla,²⁶
 M. Scornajenghi,^{41b,41a} F. Scuri,^{70a} F. Scutti,¹⁰³ L. M. Scyboz,¹¹⁴ C. D. Sebastiani,^{71a,71b} P. Seema,¹⁹ S. C. Seidel,¹¹⁷
 A. Seiden,¹⁴⁵ T. Seiss,³⁷ J. M. Seixas,^{79b} G. Sekhniaidze,^{68a} K. Sekhon,¹⁰⁴ S. J. Sekula,⁴² N. Semprini-Cesari,^{23b,23a} S. Sen,⁴⁸
 S. Senkin,³⁸ C. Serfon,¹³³ L. Serin,¹³¹ L. Serkin,^{65a,65b} M. Sessa,^{59a} H. Severini,¹²⁷ F. Sforza,¹⁶⁹ A. Sfyrila,⁵³ E. Shabalina,⁵²
 J. D. Shahinian,¹⁴⁵ N. W. Shaikh,^{44a,44b} L. Y. Shan,^{15a} R. Shang,¹⁷² J. T. Shank,²⁵ M. Shapiro,¹⁸ A. Sharma,¹³⁴ A. S. Sharma,¹
 P. B. Shatalov,¹¹⁰ K. Shaw,¹⁵⁵ S. M. Shaw,⁹⁹ A. Shcherbakova,¹³⁷ Y. Shen,¹²⁷ N. Sherafati,³⁴ A. D. Sherman,²⁵
 P. Sherwood,⁹³ L. Shi,^{157,nn} S. Shimizu,⁸⁰ C. O. Shimmin,¹⁸² Y. Shimogama,¹⁷⁸ M. Shimojima,¹¹⁵ I. P. J. Shipsey,¹³⁴
 S. Shirabe,⁸⁶ M. Shiyakova,⁷⁸ J. Shlomi,¹⁷⁹ A. Shmeleva,¹⁰⁹ D. Shoaleh Saadi,¹⁰⁸ M. J. Shochet,³⁷ S. Shojaii,¹⁰³
 D. R. Shope,¹²⁷ S. Shrestha,¹²⁵ E. Shulga,¹¹¹ P. Sicho,¹⁴⁰ A. M. Sickles,¹⁷² P. E. Sidebo,¹⁵³ E. Sideras Haddad,^{33c}
 O. Sidiropoulou,³⁶ A. Sidoti,^{23b,23a} F. Siegert,⁴⁷ Dj. Sijacki,¹⁶ J. Silva,^{139a} M. Silva Jr.,¹⁸⁰ M. V. Silva Oliveira,^{79a}
 S. B. Silverstein,^{44a} S. Simion,¹³¹ E. Simioni,⁹⁸ M. Simon,⁹⁸ R. Simoniello,⁹⁸ P. Sinervo,¹⁶⁶ N. B. Sinev,¹³⁰ M. Sioli,^{23b,23a}
 G. Siragusa,¹⁷⁶ I. Siral,¹⁰⁴ S. Yu. Sivoklov,¹¹² J. Sjölin,^{44a,44b} P. Skubic,¹²⁷ M. Slater,²¹ T. Slavicek,¹⁴¹ M. Slawinska,⁸³
 K. Sliwa,¹⁶⁹ R. Slovak,¹⁴² V. Smakhtin,¹⁷⁹ B. H. Smart,⁵ J. Smiesko,^{28a} N. Smirnov,¹¹¹ S. Yu. Smirnov,¹¹¹ Y. Smirnov,¹¹¹
 L. N. Smirnova,^{112,oo} O. Smirnova,⁹⁵ J. W. Smith,⁵² M. Smizanska,⁸⁸ K. Smolek,¹⁴¹ A. Smykiewicz,⁸³ A. A. Snesev,¹⁰⁹
 I. M. Snyder,¹³⁰ S. Snyder,²⁹ R. Sobie,^{175,m} A. M. Soffa,¹⁷⁰ A. Soffer,¹⁶⁰ A. Søggaard,⁴⁹ D. A. Soh,¹⁵⁷ G. Sokhrannyi,⁹⁰
 C. A. Solans Sanchez,³⁶ M. Solar,¹⁴¹ E. Yu. Soldatov,¹¹¹ U. Soldevila,¹⁷³ A. A. Solodkov,¹²² A. Soloshenko,⁷⁸
 O. V. Solovyanov,¹²² V. Solovyev,¹³⁷ P. Sommer,¹⁴⁸ H. Son,¹⁶⁹ W. Song,¹⁴³ W. Y. Song,^{167b} A. Sopczak,¹⁴¹ F. Sopkova,^{28b}
 C. L. Sotiropoulou,^{70a,70b} S. Sottocornola,^{69a,69b} R. Soualah,^{65a,65c,pp} A. M. Soukharev,^{121b,121a} D. South,⁴⁵ B. C. Sowden,⁹²
 S. Spagnolo,^{66a,66b} M. Spalla,¹¹⁴ M. Spangenberg,¹⁷⁷ F. Spanò,⁹² D. Sperlich,¹⁹ T. M. Spieker,^{60a} R. Spighi,^{23b} G. Spigo,³⁶
 L. A. Spiller,¹⁰³ D. P. Spiteri,⁵⁶ M. Spousta,¹⁴² A. Stabile,^{67a,67b} R. Stamen,^{60a} S. Stamm,¹⁹ E. Stanecka,⁸³ R. W. Stanek,⁶
 C. Stancu,^{73a} B. Stanislaus,¹³⁴ M. M. Stanitzki,⁴⁵ B. Stapf,¹¹⁹ S. Stapnes,¹³³ E. A. Starchenko,¹²² G. H. Stark,³⁷ J. Stark,⁵⁷
 S. H. Stark,⁴⁰ P. Staroba,¹⁴⁰ P. Starovoitov,^{60a} S. Stärz,³⁶ R. Staszewski,⁸³ M. Stegler,⁴⁵ P. Steinberg,²⁹ B. Stelzer,¹⁵¹
 H. J. Stelzer,³⁶ O. Stelzer-Chilton,^{167a} H. Stenzel,⁵⁵ T. J. Stevenson,¹⁵⁵ G. A. Stewart,³⁶ M. C. Stockton,³⁶ G. Stoica,^{27b}
 P. Stolte,⁵² S. Stonjek,¹¹⁴ A. Straessner,⁴⁷ J. Strandberg,¹⁵³ S. Strandberg,^{44a,44b} M. Strauss,¹²⁷ P. Strizenec,^{28b} R. Ströhmer,¹⁷⁶
 D. M. Strom,¹³⁰ R. Stroynowski,⁴² A. Strubig,⁴⁹ S. A. Stucci,²⁹ B. Stugu,¹⁷ J. Stupak,¹²⁷ N. A. Styles,⁴⁵ D. Su,¹⁵² J. Su,¹³⁸
 S. Suchek,^{60a} Y. Sugaya,¹³² M. Suk,¹⁴¹ V. V. Sulin,¹⁰⁹ M. J. Sullivan,⁸⁹ D. M. S. Sultan,⁵³ S. Sultansoy,^{4c} T. Sumida,⁸⁴
 S. Sun,¹⁰⁴ X. Sun,³ K. Suruliz,¹⁵⁵ C. J. E. Suster,¹⁵⁶ M. R. Sutton,¹⁵⁵ S. Suzuki,⁸⁰ M. Svatos,¹⁴⁰ M. Swiatlowski,³⁷
 S. P. Swift,² A. Sydorenko,⁹⁸ I. Sykora,^{28a} T. Sykora,¹⁴² D. Ta,⁹⁸ K. Tackmann,⁴⁵ J. Taenzer,¹⁶⁰ A. Taffard,¹⁷⁰ R. Tahirout,^{167a}
 E. Tahirovic,⁹¹ N. Taiblum,¹⁶⁰ H. Takai,²⁹ R. Takashima,⁸⁵ E. H. Takasugi,¹¹⁴ K. Takeda,⁸¹ T. Takeshita,¹⁴⁹ Y. Takubo,⁸⁰
 M. Talby,¹⁰⁰ A. A. Talyshv,^{121b,121a} J. Tanaka,¹⁶² M. Tanaka,¹⁶⁴ R. Tanaka,¹³¹ B. B. Tannenwald,¹²⁵ S. Tapia Araya,^{146b}
 S. Tapprogge,⁹⁸ A. Tarek Abouelfadl Mohamed,¹³⁵ S. Tarem,¹⁵⁹ G. Tarna,^{27b,p} G. F. Tartarelli,^{67a} P. Tas,¹⁴² M. Tasevsky,¹⁴⁰
 T. Tashiro,⁸⁴ E. Tassi,^{41b,41a} A. Tavares Delgado,^{139a,139b} Y. Tayalati,^{35e} A. C. Taylor,¹¹⁷ A. J. Taylor,⁴⁹ G. N. Taylor,¹⁰³
 P. T. E. Taylor,¹⁰³ W. Taylor,^{167b} A. S. Tee,⁸⁸ P. Teixeira-Dias,⁹² H. Ten Kate,³⁶ J. J. Teoh,¹¹⁹ S. Terada,⁸⁰ K. Terashi,¹⁶²
 J. Terron,⁹⁷ S. Terzo,¹⁴ M. Testa,⁵⁰ R. J. Teuscher,^{166,m} S. J. Thais,¹⁸² T. Thevenaux-Pelzer,⁴⁵ F. Thiele,⁴⁰ D. W. Thomas,⁹²
 J. P. Thomas,²¹ A. S. Thompson,⁵⁶ P. D. Thompson,²¹ L. A. Thomsen,¹⁸² E. Thomson,¹³⁶ Y. Tian,³⁹ R. E. Ticse Torres,⁵²
 V. O. Tikhomirov,^{109,qq} Yu. A. Tikhonov,^{121b,121a} S. Timoshenko,¹¹¹ P. Tipton,¹⁸² S. Tisserant,¹⁰⁰ K. Todome,¹⁶⁴
 S. Todorova-Nova,⁵ S. Todt,⁴⁷ J. Tojo,⁸⁶ S. Tokár,^{28a} K. Tokushuku,⁸⁰ E. Tolley,¹²⁵ K. G. Tomiwa,^{33c} M. Tomoto,¹¹⁶
 L. Tompkins,¹⁵² K. Toms,¹¹⁷ B. Tong,⁵⁸ P. Tornambe,⁵¹ E. Torrence,¹³⁰ H. Torres,⁴⁷ E. Torró Pastor,¹⁴⁷ C. Toscirri,¹³⁴
 J. Toth,^{100,rr} F. Touchard,¹⁰⁰ D. R. Tovey,¹⁴⁸ C. J. Treado,¹²³ T. Trefzger,¹⁷⁶ F. Tresoldi,¹⁵⁵ A. Tricoli,²⁹ I. M. Trigger,^{167a}
 S. Trincz-Duvold,¹³⁵ M. F. Tripiana,¹⁴ W. Trischuk,¹⁶⁶ B. Trocme,⁵⁷ A. Trofymov,¹³¹ C. Troncon,^{67a} M. Trovatelli,¹⁷⁵
 F. Trovato,¹⁵⁵ L. Truong,^{33b} M. Trzebinski,⁸³ A. Trzupek,⁸³ F. Tsai,⁴⁵ J. C-L. Tseng,¹³⁴ P. V. Tsiarshka,¹⁰⁶ A. Tsirigotis,¹⁶¹
 N. Tsirintanis,⁹ V. Tsiskaridze,¹⁵⁴ E. G. Tskhadadze,^{158a} I. I. Tsukerman,¹¹⁰ V. Tsulaia,¹⁸ S. Tsuno,⁸⁰ D. Tsybychev,¹⁵⁴
 Y. Tu,^{62b} A. Tudorache,^{27b} V. Tudorache,^{27b} T. T. Tulbure,^{27a} A. N. Tuna,⁵⁸ S. Turchikhin,⁷⁸ D. Turgeman,¹⁷⁹
 I. Turk Cakir,^{4b,ss} R. T. Turra,^{67a} P. M. Tuts,³⁹ E. Tzovara,⁹⁸ G. Uccielli,^{23b,23a} I. Ueda,⁸⁰ M. Ughetto,^{44a,44b} F. Ukegawa,¹⁶⁸

G. Unal,³⁶ A. Undrus,²⁹ G. Unel,¹⁷⁰ F. C. Ungaro,¹⁰³ Y. Unno,⁸⁰ K. Uno,¹⁶² J. Urban,^{28b} P. Urquijo,¹⁰³ P. Urrejola,⁹⁸ G. Usai,⁸
 J. Usui,⁸⁰ L. Vacavant,¹⁰⁰ V. Vacek,¹⁴¹ B. Vachon,¹⁰² K. O. H. Vadla,¹³³ A. Vaidya,⁹³ C. Valderanis,¹¹³
 E. Valdes Santurio,^{44a,44b} M. Valente,⁵³ S. Valentineti,^{23b,23a} A. Valero,¹⁷³ L. Valéry,⁴⁵ R. A. Vallance,²¹ A. Vallier,⁵
 J. A. Valls Ferrer,¹⁷³ T. R. Van Daalen,¹⁴ H. Van der Graaf,¹¹⁹ P. Van Gemmeren,⁶ J. Van Nieuwkoop,¹⁵¹ I. Van Vulpen,¹¹⁹
 M. Vanadia,^{72a,72b} W. Vandelli,³⁶ A. Vaniachine,¹⁶⁵ P. Vankov,¹¹⁹ R. Vari,^{71a} E. W. Varnes,⁷ C. Varni,^{54b,54a} T. Varol,⁴²
 D. Varouchas,¹³¹ K. E. Varvell,¹⁵⁶ G. A. Vazquez,^{146b} J. G. Vazquez,¹⁸² F. Vazeille,³⁸ D. Vazquez Furelos,¹⁴
 T. Vazquez Schroeder,³⁶ J. Veatch,⁵² V. Vecchio,^{73a,73b} L. M. Veloce,¹⁶⁶ F. Veloso,^{139a,139c} S. Veneziano,^{71a} A. Ventura,^{66a,66b}
 M. Venturi,¹⁷⁵ N. Venturi,³⁶ V. Vercesi,^{69a} M. Verducci,^{73a,73b} C. M. Vergel Infante,⁷⁷ C. Vergis,²⁴ W. Verkerke,¹¹⁹
 A. T. Vermeulen,¹¹⁹ J. C. Vermeulen,¹¹⁹ M. C. Vetterli,^{151,d} N. Viaux Maira,^{146b} M. Vicente Barreto Pinto,⁵³ I. Vichou,^{172,a}
 T. Vickey,¹⁴⁸ O. E. Vickey Boeriu,¹⁴⁸ G. H. A. Viehhauser,¹³⁴ S. Viel,¹⁸ L. Vigani,¹³⁴ M. Villa,^{23b,23a}
 M. Villaplana Perez,^{67a,67b} E. Vilucchi,⁵⁰ M. G. Vincet,³⁴ V. B. Vinogradov,⁷⁸ A. Vishwakarma,⁴⁵ C. Vittori,^{23b,23a}
 I. Vivarelli,¹⁵⁵ S. Vlachos,¹⁰ M. Vogel,¹⁸¹ P. Vokac,¹⁴¹ G. Volpi,¹⁴ S. E. von Buddenbrock,^{33c} E. Von Toerne,²⁴ V. Vorobel,¹⁴²
 K. Vorobev,¹¹¹ M. Vos,¹⁷³ J. H. Vosseveld,⁸⁹ N. Vranjes,¹⁶ M. Vranjes Milosavljevic,¹⁶ V. Vrba,¹⁴¹ M. Vreeswijk,¹¹⁹
 T. Šfiligoj,⁹⁰ R. Vuillermet,³⁶ I. Vukotic,³⁷ T. Ženiš,^{28a} L. Živković,¹⁶ P. Wagner,²⁴ W. Wagner,¹⁸¹ J. Wagner-Kuhr,¹¹³
 H. Wahlberg,⁸⁷ S. Wahrmund,⁴⁷ K. Wakamiya,⁸¹ V. M. Walbrecht,¹¹⁴ J. Walder,⁸⁸ R. Walker,¹¹³ S. D. Walker,⁹²
 W. Walkowiak,¹⁵⁰ V. Wallangen,^{44a,44b} A. M. Wang,⁵⁸ C. Wang,^{59b,p} F. Wang,¹⁸⁰ H. Wang,¹⁸ H. Wang,³ J. Wang,¹⁵⁶
 J. Wang,^{60b} P. Wang,⁴² Q. Wang,¹²⁷ R.-J. Wang,¹³⁵ R. Wang,^{59a} R. Wang,⁶ S. M. Wang,¹⁵⁷ W. T. Wang,^{59a} W. Wang,^{15c,tt}
 W. X. Wang,^{59a,tt} Y. Wang,^{59a,ff} Z. Wang,^{59c} C. Wanotayaroj,⁴⁵ A. Warburton,¹⁰² C. P. Ward,³² D. R. Wardrope,⁹³
 A. Washbrook,⁴⁹ P. M. Watkins,²¹ A. T. Watson,²¹ M. F. Watson,²¹ G. Watts,¹⁴⁷ S. Watts,⁹⁹ B. M. Waugh,⁹³ A. F. Webb,¹¹
 S. Webb,⁹⁸ C. Weber,¹⁸² M. S. Weber,²⁰ S. A. Weber,³⁴ S. M. Weber,^{60a} A. R. Weidberg,¹³⁴ B. Weinert,⁶⁴ J. Weingarten,⁴⁶
 M. Weirich,⁹⁸ C. Weiser,⁵¹ P. S. Wells,³⁶ T. Wenaus,²⁹ T. Wengler,³⁶ S. Wenig,³⁶ N. Wermes,²⁴ M. D. Werner,⁷⁷ P. Werner,³⁶
 M. Wessels,^{60a} T. D. Weston,²⁰ K. Whalen,¹³⁰ N. L. Whallon,¹⁴⁷ A. M. Wharton,⁸⁸ A. S. White,¹⁰⁴ A. White,⁸ M. J. White,¹
 R. White,^{146b} D. Whiteson,¹⁷⁰ B. W. Whitmore,⁸⁸ F. J. Wickens,¹⁴³ W. Wiedenmann,¹⁸⁰ M. Wielers,¹⁴³ C. Wiglesworth,⁴⁰
 L. A. M. Wiik-Fuchs,⁵¹ F. Wilk,⁹⁹ H. G. Wilkens,³⁶ L. J. Wilkins,⁹² H. H. Williams,¹³⁶ S. Williams,³² C. Willis,¹⁰⁵
 S. Willocq,¹⁰¹ J. A. Wilson,²¹ I. Wingerter-Seez,⁵ E. Winkels,¹⁵⁵ F. Winklmeier,¹³⁰ O. J. Winston,¹⁵⁵ B. T. Winter,⁵¹
 M. Wittgen,¹⁵² M. Wobisch,⁹⁴ A. Wolf,⁹⁸ T. M. H. Wolf,¹¹⁹ R. Wolff,¹⁰⁰ M. W. Wolter,⁸³ H. Wolters,^{139a,139c}
 V. W. S. Wong,¹⁷⁴ N. L. Woods,¹⁴⁵ S. D. Worm,²¹ B. K. Wosiek,⁸³ K. W. Woźniak,⁸³ K. Wraight,⁵⁶ M. Wu,³⁷ S. L. Wu,¹⁸⁰
 X. Wu,⁵³ Y. Wu,^{59a} T. R. Wyatt,⁹⁹ B. M. Wynne,⁴⁹ S. Xella,⁴⁰ Z. Xi,¹⁰⁴ L. Xia,¹⁷⁷ D. Xu,^{15a} H. Xu,^{59a,p} L. Xu,²⁹ T. Xu,¹⁴⁴
 W. Xu,¹⁰⁴ B. Yabsley,¹⁵⁶ S. Yacoob,^{33a} K. Yajima,¹³² D. P. Yallup,⁹³ D. Yamaguchi,¹⁶⁴ Y. Yamaguchi,¹⁶⁴ A. Yamamoto,⁸⁰
 T. Yamanaka,¹⁶² F. Yamane,⁸¹ M. Yamatani,¹⁶² T. Yamazaki,¹⁶² Y. Yamazaki,⁸¹ Z. Yan,²⁵ H. J. Yang,^{59c,59d} H. T. Yang,¹⁸
 S. Yang,⁷⁶ Y. Yang,¹⁶² Z. Yang,¹⁷ W.-M. Yao,¹⁸ Y. C. Yap,⁴⁵ Y. Yasu,⁸⁰ E. Yatsenko,^{59c,59d} J. Ye,⁴² S. Ye,²⁹ I. Yeletsikh,⁷⁸
 E. Yigitbasi,²⁵ E. Yildirim,⁹⁸ K. Yorita,¹⁷⁸ K. Yoshihara,¹³⁶ C. J. S. Young,³⁶ C. Young,¹⁵² J. Yu,⁷⁷ J. Yu,⁸ X. Yue,^{60a}
 S. P. Y. Yuen,²⁴ B. Zabinski,⁸³ G. Zacharis,¹⁰ E. Zaffaroni,⁵³ R. Zaidan,¹⁴ A. M. Zaitsev,^{122,jj} T. Zakareishvili,^{158b}
 N. Zakharchuk,³⁴ J. Zalieckas,¹⁷ S. Zambito,⁵⁸ D. Zanzi,³⁶ D. R. Zaripovas,⁵⁶ S. V. Zeiβner,⁴⁶ C. Zeitnitz,¹⁸¹ G. Zemaityte,¹³⁴
 J. C. Zeng,¹⁷² Q. Zeng,¹⁵² O. Zenin,¹²² D. Zerwas,¹³¹ M. Zgubić,¹³⁴ D. F. Zhang,^{59b} D. Zhang,¹⁰⁴ F. Zhang,¹⁸⁰ G. Zhang,^{59a}
 G. Zhang,^{15b} H. Zhang,^{15c} J. Zhang,⁶ L. Zhang,^{15c} L. Zhang,^{59a} M. Zhang,¹⁷² P. Zhang,^{15c} R. Zhang,^{59a} R. Zhang,²⁴
 X. Zhang,^{59b} Y. Zhang,^{15a,15d} Z. Zhang,¹³¹ P. Zhao,⁴⁸ Y. Zhao,^{59b,131,x} Z. Zhao,^{59a} A. Zhemchugov,⁷⁸ Z. Zheng,¹⁰⁴
 D. Zhong,¹⁷² B. Zhou,¹⁰⁴ C. Zhou,¹⁸⁰ L. Zhou,⁴² M. S. Zhou,^{15a,15d} M. Zhou,¹⁵⁴ N. Zhou,^{59c} Y. Zhou,⁷ C. G. Zhu,^{59b}
 H. L. Zhu,^{59a} H. Zhu,^{15a} J. Zhu,¹⁰⁴ Y. Zhu,^{59a} X. Zhuang,^{15a} K. Zhukov,¹⁰⁹ V. Zhulanov,^{121b,121a} A. Zibell,¹⁷⁶ D. Zieminska,⁶⁴
 N. I. Zimine,⁷⁸ S. Zimmermann,⁵¹ Z. Zinonos,¹¹⁴ M. Zinser,⁹⁸ M. Ziolkowski,¹⁵⁰ G. Zobernig,¹⁸⁰ A. Zoccoli,^{23b,23a}
 K. Zoch,⁵² T. G. Zorbas,¹⁴⁸ R. Zou,³⁷ M. Zur Nedden,¹⁹ and L. Zwalinski³⁶

(ATLAS Collaboration)

¹*Department of Physics, University of Adelaide, Adelaide, Australia*
²*Physics Department, SUNY Albany, Albany, New York, USA*
³*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
^{4a}*Department of Physics, Ankara University, Ankara, Turkey*
^{4b}*Istanbul Aydin University, Istanbul, Turkey*

- ^{4c}*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
- ⁵*LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
- ⁶*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*
- ⁷*Department of Physics, University of Arizona, Tucson, Arizona, USA*
- ⁸*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA*
- ⁹*Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
- ¹⁰*Physics Department, National Technical University of Athens, Zografou, Greece*
- ¹¹*Department of Physics, University of Texas at Austin, Austin, Texas, USA*
- ^{12a}*Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
- ^{12b}*Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
- ^{12c}*Department of Physics, Bogazici University, Istanbul, Turkey*
- ^{12d}*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
- ¹³*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
- ¹⁴*Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
- ^{15a}*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
- ^{15b}*Physics Department, Tsinghua University, Beijing, China*
- ^{15c}*Department of Physics, Nanjing University, Nanjing, China*
- ^{15d}*University of Chinese Academy of Science (UCAS), Beijing, China*
- ¹⁶*Institute of Physics, University of Belgrade, Belgrade, Serbia*
- ¹⁷*Department for Physics and Technology, University of Bergen, Bergen, Norway*
- ¹⁸*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
- ¹⁹*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
- ²⁰*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
- ²¹*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
- ²²*Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogota, Colombia*
- ^{23a}*INFN Bologna and Università di Bologna, Dipartimento di Fisica, Italy*
- ^{23b}*INFN Sezione di Bologna, Italy*
- ²⁴*Physikalisches Institut, Universität Bonn, Bonn, Germany*
- ²⁵*Department of Physics, Boston University, Boston, Massachusetts, USA*
- ²⁶*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
- ^{27a}*Transilvania University of Brasov, Brasov, Romania*
- ^{27b}*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
- ^{27c}*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
- ^{27d}*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania*
- ^{27e}*University Politehnica Bucharest, Bucharest, Romania*
- ^{27f}*West University in Timisoara, Timisoara, Romania*
- ^{28a}*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
- ^{28b}*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
- ²⁹*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
- ³⁰*Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
- ³¹*California State University, California, USA*
- ³²*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
- ^{33a}*Department of Physics, University of Cape Town, Cape Town, South Africa*
- ^{33b}*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*
- ^{33c}*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
- ³⁴*Department of Physics, Carleton University, Ottawa, Ontario, Canada*
- ^{35a}*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies-Université Hassan II, Casablanca, Morocco*
- ^{35b}*Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco*
- ^{35c}*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*
- ^{35d}*Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco*
- ^{35e}*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
- ³⁶*CERN, Geneva, Switzerland*
- ³⁷*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
- ³⁸*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
- ³⁹*Nevis Laboratory, Columbia University, Irvington, New York, USA*
- ⁴⁰*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
- ^{41a}*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- ^{41b}*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
- ⁴²*Physics Department, Southern Methodist University, Dallas, Texas, USA*

- ⁴³Physics Department, University of Texas at Dallas, Richardson, Texas, USA
^{44a}Department of Physics, Stockholm University, Sweden
^{44b}Oskar Klein Centre, Stockholm, Sweden
⁴⁵Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany
⁴⁶Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
⁴⁷Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
⁴⁸Department of Physics, Duke University, Durham, North Carolina, USA
⁴⁹SUPA-School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
⁵⁰INFN e Laboratori Nazionali di Frascati, Frascati, Italy
⁵¹Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
⁵²II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany
⁵³Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland
^{54a}Dipartimento di Fisica, Università di Genova, Genova, Italy
^{54b}INFN Sezione di Genova, Italy
⁵⁵II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
⁵⁶SUPA-School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
⁵⁷LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France
⁵⁸Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA
^{59a}Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China
^{59b}Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China
^{59c}School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai, China
^{59d}Tsung-Dao Lee Institute, Shanghai, China
^{60a}Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
^{60b}Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
⁶¹Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
^{62a}Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
^{62b}Department of Physics, University of Hong Kong, Hong Kong, China
^{62c}Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
⁶³Department of Physics, National Tsing Hua University, Hsinchu, Taiwan
⁶⁴Department of Physics, Indiana University, Bloomington, Indiana, USA
^{65a}INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy
^{65b}ICTP, Trieste, Italy
^{65c}Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy
^{66a}INFN Sezione di Lecce, Italy
^{66b}Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
^{67a}INFN Sezione di Milano, Italy
^{67b}Dipartimento di Fisica, Università di Milano, Milano, Italy
^{68a}INFN Sezione di Napoli, Italy
^{68b}Dipartimento di Fisica, Università di Napoli, Napoli, Italy
^{69a}INFN Sezione di Pavia, Italy
^{69b}Dipartimento di Fisica, Università di Pavia, Pavia, Italy
^{70a}INFN Sezione di Pisa, Italy
^{70b}Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
^{71a}INFN Sezione di Roma, Italy
^{71b}Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
^{72a}INFN Sezione di Roma Tor Vergata, Italy
^{72b}Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
^{73a}INFN Sezione di Roma Tre, Italy
^{73b}Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
^{74a}INFN-TIFPA, Italy
^{74b}Università degli Studi di Trento, Trento, Italy
⁷⁵Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
⁷⁶University of Iowa, Iowa City, Iowa, USA
⁷⁷Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA
⁷⁸Joint Institute for Nuclear Research, Dubna, Russia
^{79a}Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil
^{79b}Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil

- ^{79c}*Universidade Federal de São João del Rei (UFSJ), São João del Rei, Brazil*
- ^{79d}*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
- ⁸⁰*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
- ⁸¹*Graduate School of Science, Kobe University, Kobe, Japan*
- ^{82a}*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
- ^{82b}*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
- ⁸³*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
- ⁸⁴*Faculty of Science, Kyoto University, Kyoto, Japan*
- ⁸⁵*Kyoto University of Education, Kyoto, Japan*
- ⁸⁶*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
- ⁸⁷*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
- ⁸⁸*Physics Department, Lancaster University, Lancaster, United Kingdom*
- ⁸⁹*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
- ⁹⁰*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
- ⁹¹*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
- ⁹²*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
- ⁹³*Department of Physics and Astronomy, University College London, London, United Kingdom*
- ⁹⁴*Louisiana Tech University, Ruston, Louisiana, USA*
- ⁹⁵*Fysiska institutionen, Lunds universitet, Lund, Sweden*
- ⁹⁶*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
- ⁹⁷*Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
- ⁹⁸*Institut für Physik, Universität Mainz, Mainz, Germany*
- ⁹⁹*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
- ¹⁰⁰*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
- ¹⁰¹*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*
- ¹⁰²*Department of Physics, McGill University, Montreal, Quebec, Canada*
- ¹⁰³*School of Physics, University of Melbourne, Victoria, Australia*
- ¹⁰⁴*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*
- ¹⁰⁵*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*
- ¹⁰⁶*B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
- ¹⁰⁷*Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*
- ¹⁰⁸*Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada*
- ¹⁰⁹*P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
- ¹¹⁰*Institute for Theoretical and Experimental Physics of the National Research Centre Kurchatov Institute, Moscow, Russia*
- ¹¹¹*National Research Nuclear University MEPhI, Moscow, Russia*
- ¹¹²*D.V. Skobel'syn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
- ¹¹³*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
- ¹¹⁴*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
- ¹¹⁵*Nagasaki Institute of Applied Science, Nagasaki, Japan*
- ¹¹⁶*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
- ¹¹⁷*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
- ¹¹⁸*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
- ¹¹⁹*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
- ¹²⁰*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*
- ^{121a}*Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, Russia*
- ^{121b}*Novosibirsk State University Novosibirsk, Russia*
- ¹²²*Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia*
- ¹²³*Department of Physics, New York University, New York, New York, USA*
- ¹²⁴*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*
- ¹²⁵*Ohio State University, Columbus, Ohio, USA*
- ¹²⁶*Faculty of Science, Okayama University, Okayama, Japan*
- ¹²⁷*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*
- ¹²⁸*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*
- ¹²⁹*Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic*
- ¹³⁰*Center for High Energy Physics, University of Oregon, Eugene, Oregon, USA*
- ¹³¹*LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France*
- ¹³²*Graduate School of Science, Osaka University, Osaka, Japan*
- ¹³³*Department of Physics, University of Oslo, Oslo, Norway*
- ¹³⁴*Department of Physics, Oxford University, Oxford, United Kingdom*

- ¹³⁵*LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France*
- ¹³⁶*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*
- ¹³⁷*Konstantinov Nuclear Physics Institute of National Research Centre “Kurchatov Institute”, PNPI, St. Petersburg, Russia*
- ¹³⁸*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
- ^{139a}*Laboratório de Instrumentação e Física Experimental de Partículas-LIP, Portugal*
- ^{139b}*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
- ^{139c}*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*
- ^{139d}*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
- ^{139e}*Departamento de Física, Universidade do Minho, Braga, Portugal*
- ^{139f}*Universidad de Granada, Granada (Spain), Spain*
- ^{139g}*Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*
- ¹⁴⁰*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
- ¹⁴¹*Czech Technical University in Prague, Prague, Czech Republic*
- ¹⁴²*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
- ¹⁴³*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
- ¹⁴⁴*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- ¹⁴⁵*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
- ^{146a}*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
- ^{146b}*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
- ¹⁴⁷*Department of Physics, University of Washington, Seattle, Washington, USA*
- ¹⁴⁸*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
- ¹⁴⁹*Department of Physics, Shinshu University, Nagano, Japan*
- ¹⁵⁰*Department Physik, Universität Siegen, Siegen, Germany*
- ¹⁵¹*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*
- ¹⁵²*SLAC National Accelerator Laboratory, Stanford, California, USA*
- ¹⁵³*Physics Department, Royal Institute of Technology, Stockholm, Sweden*
- ¹⁵⁴*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*
- ¹⁵⁵*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
- ¹⁵⁶*School of Physics, University of Sydney, Sydney, Australia*
- ¹⁵⁷*Institute of Physics, Academia Sinica, Taipei, Taiwan*
- ^{158a}*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*
- ^{158b}*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
- ¹⁵⁹*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
- ¹⁶⁰*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
- ¹⁶¹*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
- ¹⁶²*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
- ¹⁶³*Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
- ¹⁶⁴*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
- ¹⁶⁵*Tomsk State University, Tomsk, Russia*
- ¹⁶⁶*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
- ^{167a}*TRIUMF, Vancouver, British Columbia, Canada*
- ^{167b}*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
- ¹⁶⁸*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
- ¹⁶⁹*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
- ¹⁷⁰*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
- ¹⁷¹*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
- ¹⁷²*Department of Physics, University of Illinois, Urbana, Illinois, USA*
- ¹⁷³*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia-CSIC, Valencia, Spain*
- ¹⁷⁴*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
- ¹⁷⁵*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
- ¹⁷⁶*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
- ¹⁷⁷*Department of Physics, University of Warwick, Coventry, United Kingdom*
- ¹⁷⁸*Waseda University, Tokyo, Japan*
- ¹⁷⁹*Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel*
- ¹⁸⁰*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
- ¹⁸¹*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
- ¹⁸²*Department of Physics, Yale University, New Haven, Connecticut, USA*
- ¹⁸³*Yerevan Physics Institute, Yerevan, Armenia*

^aDeceased.

^bAlso at Department of Physics, King's College London, London, United Kingdom.

^cAlso at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

^dAlso at TRIUMF, Vancouver, British Columbia, Canada.

^eAlso at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.

^fAlso at Physics Department, An-Najah National University, Nablus, Palestine.

^gAlso at Department of Physics, California State University, Fresno, USA.

^hAlso at Department of Physics, University of Fribourg, Fribourg, Switzerland.

ⁱAlso at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain.

^jAlso at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.

^kAlso at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.

^lAlso at Università di Napoli Parthenope, Napoli, Italy.

^mAlso at Institute of Particle Physics (IPP), Canada.

ⁿAlso at II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany.

^oAlso at Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania.

^pAlso at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France.

^qAlso at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.

^rAlso at Borough of Manhattan Community College, City University of New York, New York, New York, USA.

^sAlso at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.

^tAlso at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa.

^uAlso at Department of Physics, California State University, East Bay, USA.

^vAlso at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.

^wAlso at Department of Physics, University of Michigan, Ann Arbor, Michigan, USA.

^xAlso at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France.

^yAlso at Graduate School of Science, Osaka University, Osaka, Japan.

^zAlso at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.

^{aa}Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.

^{bb}Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.

^{cc}Also at CERN, Geneva, Switzerland.

^{dd}Also at Manhattan College, New York, New York, USA.

^{ee}Also at Hellenic Open University, Patras, Greece.

^{ff}Also at LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France.

^{gg}Also at The City College of New York, New York, New York, USA.

^{hh}Also at Universidad de Granada, Granada (Spain), Spain.

ⁱⁱAlso at Department of Physics, California State University, Sacramento, USA.

^{jj}Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.

^{kk}Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.

^{ll}Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.

^{mm}Also at Louisiana Tech University, Ruston, Louisiana, USA.

ⁿⁿAlso at School of Physics, Sun Yat-sen University, Guangzhou, China.

^{oo}Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.

^{pp}Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah, United Arab Emirates.

^{qq}Also at National Research Nuclear University MEPhI, Moscow, Russia.

^{rr}Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.

^{ss}Also at Giresun University, Faculty of Engineering, Giresun, Turkey.

^{tt}Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.